THE MAGAZINE THAT FEEDS MINDS

HOW IT WORKS™

SCIENCE ENVIRONMENT TECHNOLOGY TRANSPORT HISTORY SPACE

INSIDE

DEADLIEST ANIMALS
THE PLANET'S MOST DANGEROUS KILLERS

GREEK WARRIORS
How these brutal soldiers did battle

LASER PRINTERS
The device that uses a beam of light to print text and pictures

994 FACTS AND ANSWERS INSIDE

BINARY STARS
What causes the formation of star systems with twin suns?

FACIAL RECOGNITION
Discover how digital cameras can detect and identify faces

MONSTER TRUCKS
THE ENGINEERING BEHIND OVER-SIZED PICKUP TRUCKS

EARTH TO ORBIT IN 5 MINS!

SPACE PLANES

HOW YOU COULD GET INTO ORBIT ON BOARD A MACH-5 SUPERPLANE

+ LEARN ABOUT

- QUAD BIKES
- ANAESTHETIC
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- PLANKTON
- SPACE RAYS
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- AMBER

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5 TOP FACTS: FORD FIESTA RS WRC

Developed by M-Sport from the Super 2000 car, the Fiesta WRC represents the pinnacle of Ford's rally car family.

The 2011 Wales Rally GB saw Ford set a new record, with 8 of the top 10 places behind held by the marque.

A new cheaper Fiesta rally car was launched at this year's Paris motorshow, the Fiesta R5 sits just below that of the WRC in performance.

With over 300bhp coming from just 1600ccs the engine is one of the most impressive parts of the Fiesta WRC.

Taking three wins so far in 2012 the Ford Fiesta WRC looks set to continue its success next season.

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An extensive aero package contributes to downforce, keeping the car glued to the road.

A robust rollcage offers excellent crash protection for the crew.

The powerful 1.6L eco-boost turbo combines both horsepower and reliability, with 300BHP available.

355mm Brembo disc brakes give the Fiesta awesome stopping power.

FORD FIESTA RS WRC - NEW TOOL

A number of teams now drive the Fiesta WRC in the World Rally Championship and it has scored a number of victories and has been competitive with both the works rally team and a number of privateer teams.

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HOW IT WORKS

ISSUE 48

WELCOME

The magazine that feeds minds!

Page 37
Discover the unusual natural phenomenon responsible for this alien-looking landscape

Get in touch

Have YOU got a question you want answered by the How It Works team? Get in touch via:

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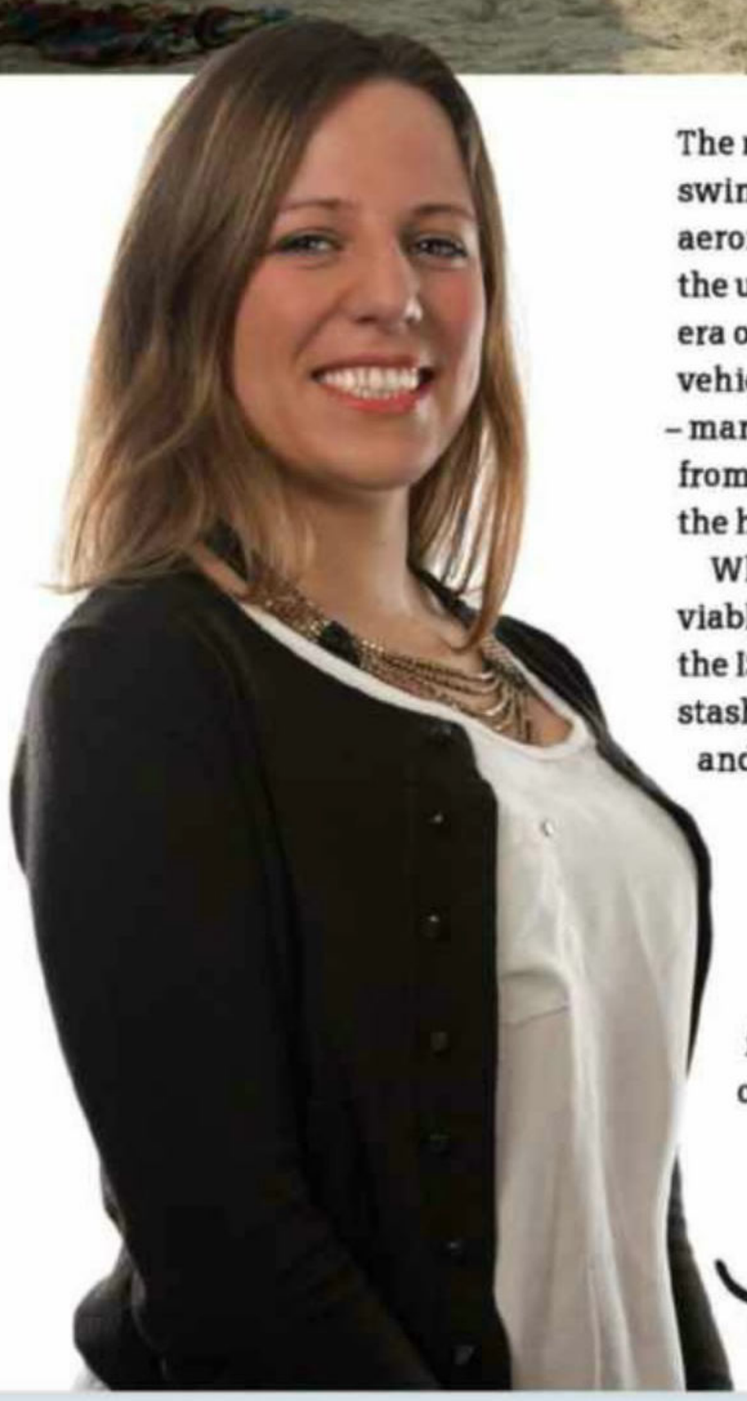

The race to get passengers into space is in full swing. The last five years have seen major aeronautics companies competing to develop the ultimate thrill ride for travellers. This new era of space flight is seeing the development of vehicles that can operate like regular aircraft – many of which are being designed to take off from runways and launch into orbit without the help of costly and often dangerous rockets.

While space agencies look for economically viable launch systems to transport payloads to the ISS and beyond, civilians with enough cash stashed in their back pockets are also ready and willing to boldly go into space.

This issue, discover the leaps already made by the four main contenders. Who will be ferrying astronauts to the ISS, which private developers offer the most enticing flight options, and will we see full flights taking paying passengers into orbit before the year is out?

Enjoy the issue.

Helen

Helen Porter
Editor

What's in store...

The huge amount of information in each issue of How It Works is organised into these key sections:

Science
Uncover the world's most amazing physics, chemistry and biology

Technology
Discover the inner workings of cool gadgets and engineering marvels

Transport
Everything from the fastest cars to the most advanced aircraft

Space
Learn about all things cosmic in the section that's truly out of this world

Environment
Explore the amazing natural wonders to be found on planet Earth

History
Step back in time and find out how things used to work in the past

Meet the team...

Robert
Features Editor
Visiting the UK's largest particle accelerator was amazing. The science it's enabling is mind-blowing.

Marcus
Designer
I was going to book a holiday to Spain but after reading our space planes feature I'll be saving up for a trip the stars.

Laura
Staff Writer
The microscopic army of cells that make up the human immune system never ceases to amaze me.

Adam
Senior Sub Editor
After reading our deadliest animals feature, I will keep a close eye out the next time I venture into the wilderness!

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The magazine that feeds m[illegible]ds!

12 SPACE PLANES

Rockets like the Space Shuttle have been the driving force behind getting off Earth for over five decades, but now a whole new breed of space transport is lining up on the runway...

"Space planes will reduce the cost of taking a payload into space"

MEET THE EXPERTS

Find out more about the writers in this month's edition of **How It Works...**

Giles Sparrow
Solar-powered spacecraft

Eco-friendly technology is not just a growing phenomenon here on Earth. Our Astronomy expert Giles takes a closer look at how the Juno spacecraft is using the Sun to reach Jupiter.

Alexandra Cheung
Neutrinos

A former employee of CERN and the Institute of Physics Alex jumped at the chance to put these subatomic particles under the microscope and reveal the impact they're having on the scientific world.

Vivienne Raper
Subterranean rivers

Geophysicist Vivienne takes us on a tour of the complex networks of caverns, tunnels and waterfalls that can exist deep underground, carved out over millennia as water runs its course.

Luis Villazon
Deadliest animals

The animal kingdom is full of beasts with the potential to inflict serious – if not mortal – damage. Luis rounds up ten of the most powerful and most cunning, with a few that may surprise you.

Jonathan O'Callaghan
Space planes

This issue Jonathan, Features Editor from our sister magazine **All About Space**, is lifting the lid on the new wave of aircraft set to take us into orbit.

Who was Charles Darwin and what did he do for science? Find out now on page 32

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72 Quad bikes

Take a look at the engineering behind these fun recreational vehicles

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A glimpse at what's inside the UK's largest lab

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Discover how the human body can learn to fight diseases

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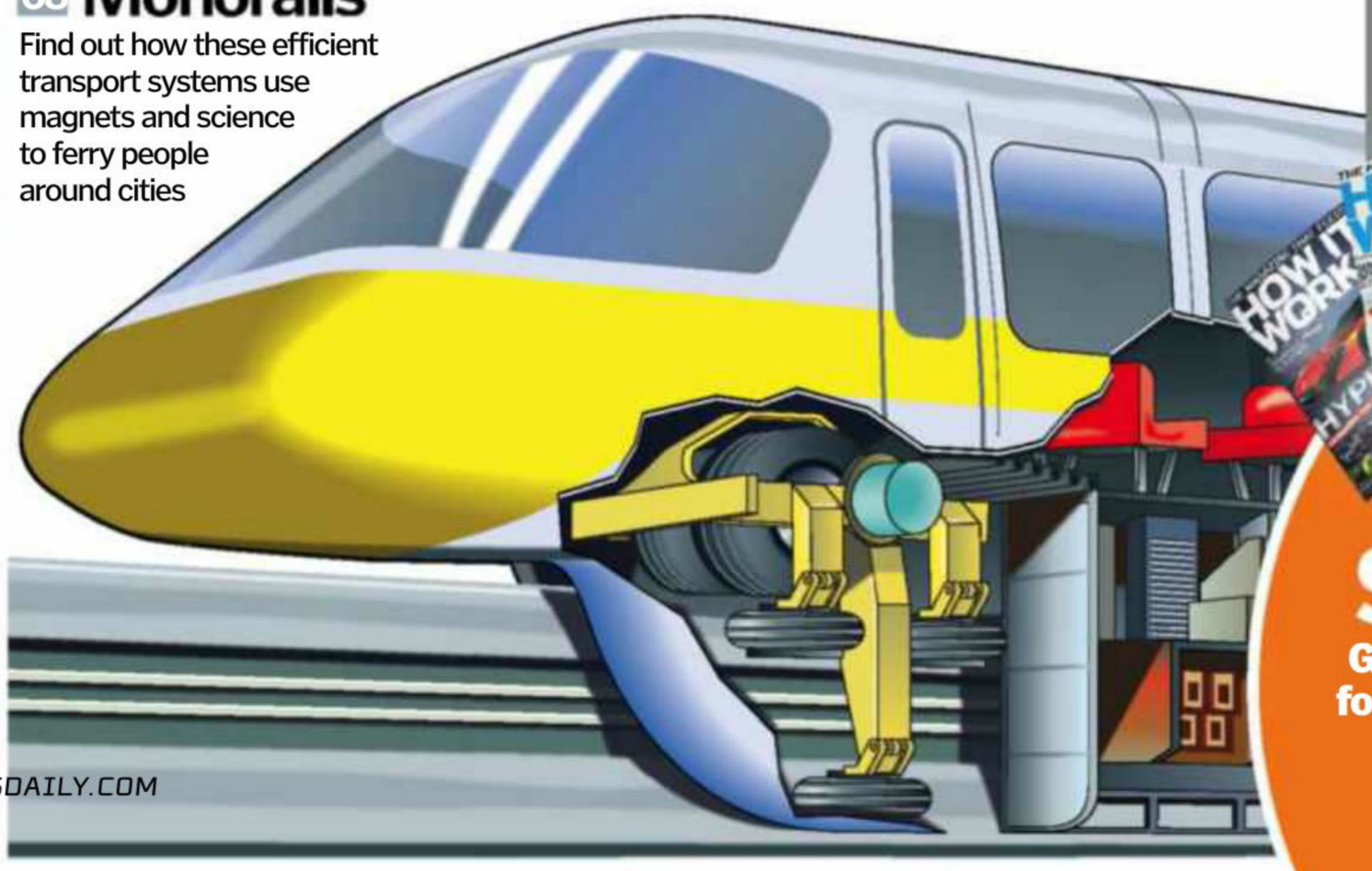

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REGULARS

GLOBAL EYE NEWS

Showcasing the incredible world we live in...

Ground control to Major Tim

The first Briton ever to be accepted into the European Astronaut Corps, Major Tim Peake, is selected for a mission to the ISS

The European Space Agency (ESA) has announced that ex-military helicopter pilot Major Tim Peake will become the first British astronaut to travel into space in over 20 years. Selected from a pool of 8,000 applicants Major Peake is to be posted to the International Space Station (ISS) for a six-month mission starting in November 2015.

There he will join the crew of Expedition 46/47 and, in addition to performing a number of extravehicular activities (or spacewalks), he will conduct complex science experiments in the Columbus laboratory module of the habitable satellite. Speaking on his appointment, Major Peake said: "I am delighted to be proposed for a long-duration mission to the International Space Station. This is another important mission for Europe and in particular a wonderful opportunity for European science, industry and education to benefit from microgravity research. Since joining the European Astronaut Corps in 2009, I have been training to work on the ISS and I am extremely grateful to the ground support teams who make it possible for us to push the boundaries of knowledge through human spaceflight and exploration."

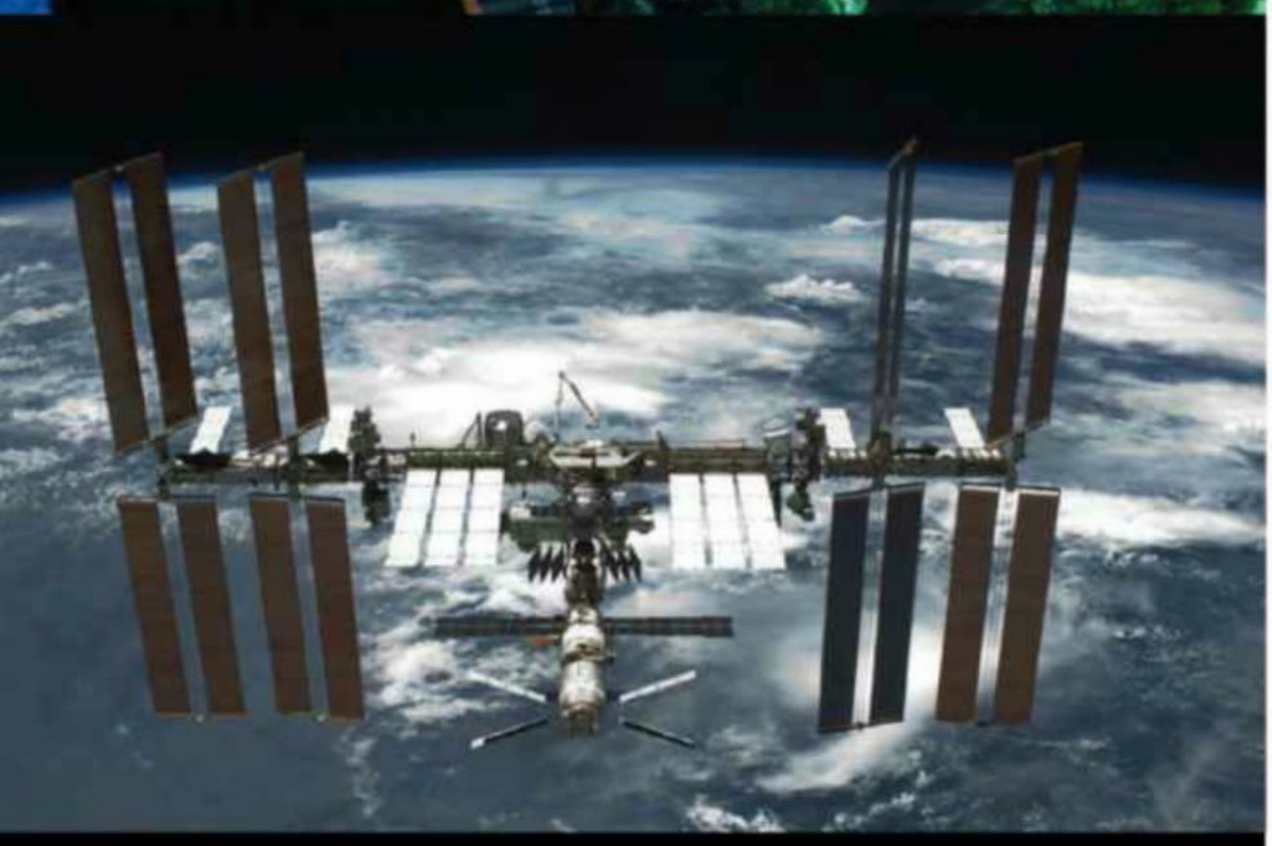
Major Peake's journey to the ISS though has not been easy. Since 2009, on top of his year-long basic astronaut training – renowned for its intensity and difficulty – Peake undertook additional training to increase his skills in weightlessness, went on a trip to an advanced cave complex to spend a week living in isolation underground and then spent almost two weeks in NASA's Extreme Environment Mission Operations (NEEMO) underwater research base. While in NEEMO, Peake took part in a course focused on asteroid exploration, which involved simulating communication delays with ground control.

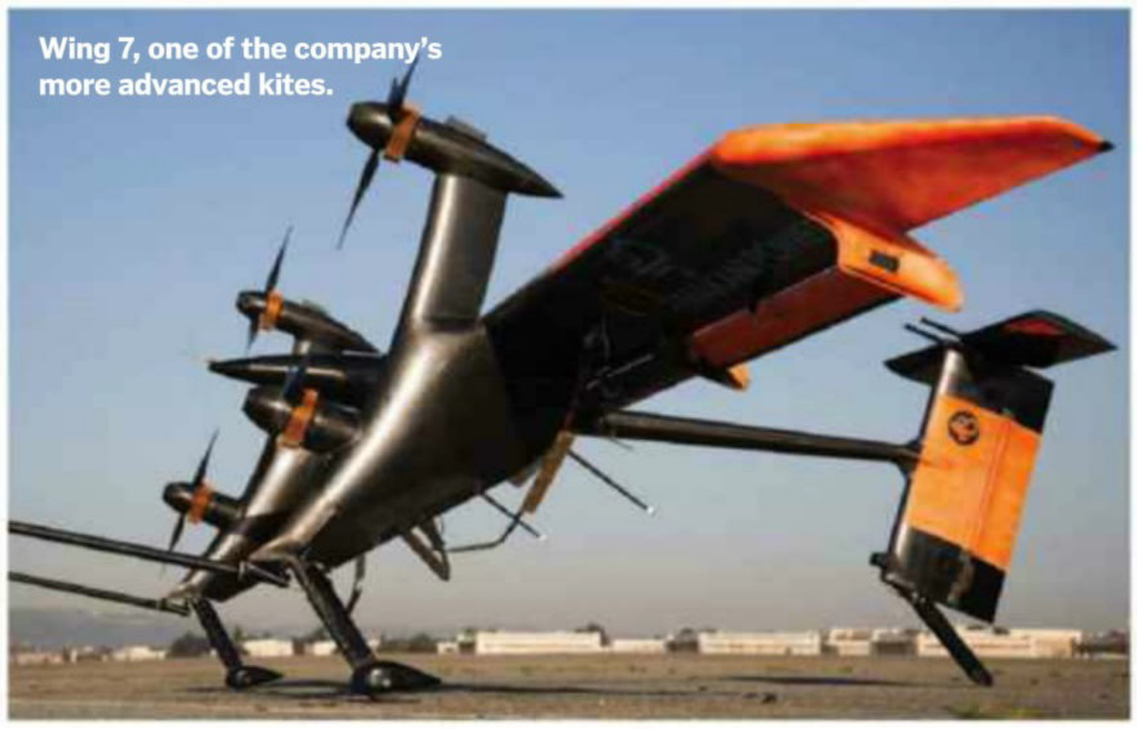
And the preparation isn't over either. Now selected, he will start his mission training with the partners of the ISS. This training will take him from the European Astronaut Centre near Cologne, Germany, to the Johnson Space Center in Houston, USA, and later on to Star City near Moscow, Russia.

Peake will be stationed on the ISS for six months

In 2011 Peake spent a week underground in a cave complex in preparation for the isolation of space

Peake taking part in a video conference call in the underwater NEEMO training base (also pictured top)



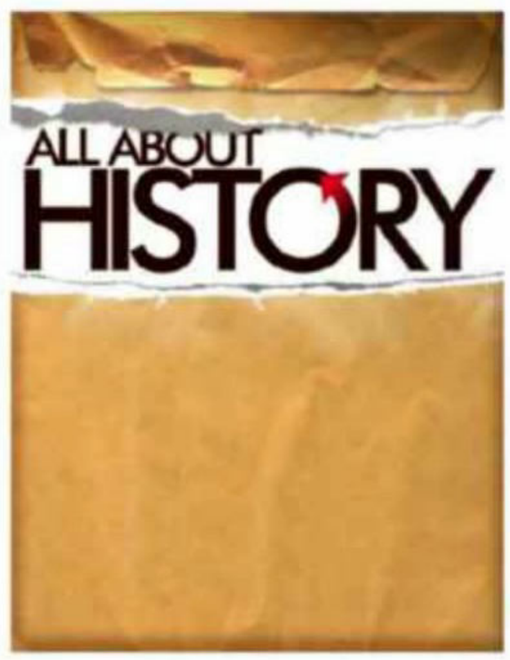


Wing 7, one of the company's more advanced kites.

Powered by kites

Google X buys pioneering kite tech

Google has bought Makani Power, a company that specialises in producing large kites with turbines mounted to their wings. Once the kite is released, these turbines will then proceed to use the high winds experienced at altitude – the tethered kites will hover at up to 600 metres above the ground – to generate electricity. Speaking on the deal, Makani said that it would provide them "with the resources to accelerate work to make wind energy cost competitive with fossil fuels." The company, now purchased, will become part of Google X, the internet giant's secretive research-and-development division.



It's about time!

Brand-new Imagine title All About History brings the past to life

27 June marks the launch of **All About History**, the accessible and entertaining magazine from the makers of **How It Works** and **All About Space**. Shaking up the currently uninspiring history market, **this beautifully conceived title** brings the people, places and events of bygone days alive. With page after page of sumptuously illustrated depictions of famous events and characters this is like no other historical magazine you've ever seen. A variety of authoritative yet accessible and well-crafted features will also capture the imagination like never before.

From the wonder of ancient civilisations to the secret histories of our greatest inventors, **All About History** delivers an exciting blend of facts and commentary about times gone by. This thrilling blast from the past is available in all major supermarkets and newsagents from 27 June.

"This beautifully conceived title brings the people, places and events of bygone days alive"

Harlequin ladybird is a 'bio weapon'

New research reveals that this colourful insect from Asia is harbouring a deadly parasite

The harlequin ladybird (Harmonia axyridis) is one of the world's most invasive insects. Originating in central Asia but now rampant throughout Europe and North America, the brightly coloured bug has now been revealed by researchers working at the Justus Liebig University in Giessen, Germany, to carry a single-celled parasite that wipes out the native seven-spot ladybird. Speaking on the publication of the results in the journal *Science*, entomologist and team leader, Andreas Vilcinskas, explained: "The situation is similar to when Europeans conquered the New World. The diseases they carried, such as smallpox, killed more native people than their weapons."

According to the report, the killer parasite exists in the eggs and larvae of all harlequin ladybirds, but in a dormant state. However due to ladybirds' penchant for eating each other's eggs, the seven-spot species unwittingly consume the parasite at which point it reactivates.

The harlequin has been a key cause of decline in native ladybirds

"The killer parasite exists in the eggs and larvae of all harlequin ladybirds"

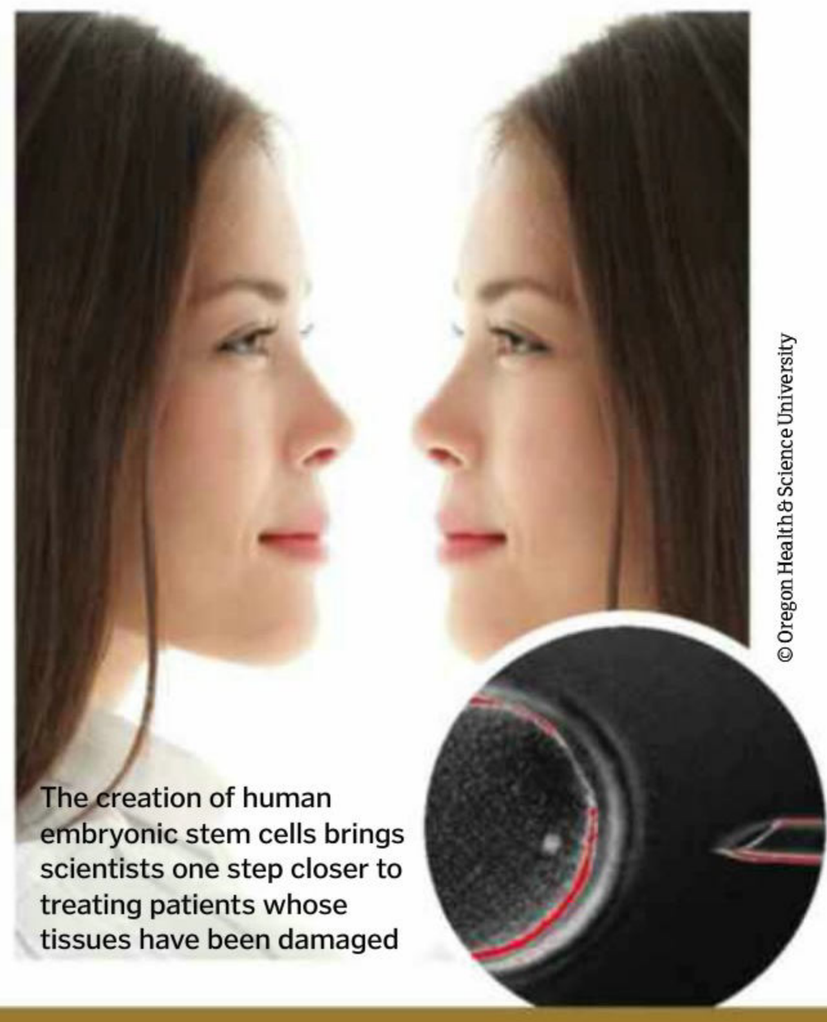
New human cloning science revealed

Research team succeeds in creating special cells that can form any tissue in the human body, opening up the future possibility of cloning human organs

A US research team working at the Oregon Health and Science University have managed to create large quantities of human embryonic stem cells – the body's master cells – from donated skin cells, overcoming a decade of failure and conjecture.

The team's report, published in science journal *Cell*, states this was achieved by overcoming such issues as the premature development of the cloned embryo – something solved by adding caffeine to each embryo's petri dish during development. Speaking on the breakthrough, research leader Shoukhrat Mitalipov said: "Our finding offers new ways of generating stem cells for patients with dysfunctional or damaged tissues and organs. Such stem cells can regenerate and replace those damaged cells and tissues and alleviate diseases that affect millions of people."

Considering the topic of therapeutic cloning in humans has long been surrounded by controversy relating to feasibility and ethicality, the team's success arguably helps re-establish the field as a viable path forward.



© Oregon Health & Science University

The creation of human embryonic stem cells brings scientists one step closer to treating patients whose tissues have been damaged

This day in history 20 June: Issue 48 goes on sale, but what else happened?

451 CE
Hun-gary for war
Roman general Flavius Aëtius fights Attila the Hun (right) at the Battle of Châlons, or Catalaunian Plains. The result is inconclusive.

1782
Seal of approval
The US Congress adopts the Great Seal of the United States of America, featuring an eagle and a pyramid topped with an eye.

1819
Pond hopping
The US hybrid ship SS Savannah (right) arrives at Liverpool, England – the first steam-propelled vessel to cross the Atlantic.

1837
New queen
Queen Victoria succeeds to the British throne after the death of William IV.

2003
Birth of Wiki
The not-for-profit organisation Wikimedia Foundation is founded in St Petersburg, FL.

Biology with a bang

Most famous for his role on science programme Bang Goes The Theory, Dr Yan Wong talks to us about Darwin, Dawkins and decoding DNA

What sparked your interest in science?
I think that everyone is to some extent curious about the world at an early age, aren't they? But as we get older, some of us seem to lose that curiosity. I guess that somehow I retained it. I was always asking questions about how things worked and why things were the way they were, and I just had the good fortune to have two biology teachers who encouraged me to learn by asking questions.

I also like arguing with people and really getting to the root of an idea, and I think that carried through into university and beyond.

One of your areas of expertise is evolutionary biology. How did you get involved in this particular field?
I think my first real introduction came from reading *The Selfish Gene*, by Richard Dawkins. It is so well written that it gets a lot of people enthused about the power of evolutionary biology. I say 'power' because the idea of evolution – and the concept of natural selection – is so simple, yet can explain a huge amount about the world around us. It also makes you think about nature in a different, more analytical way. I find that combination very intellectually satisfying.

We have an article on Charles Darwin this issue – how important was his work?
I'd say extremely important – but, of course, I'm biased! Darwin was a very inquisitive and rounded biologist, but at the same time comes over as a very enlightened and humble man – the sort of person you'd really like to meet.

In his lifetime he investigated lots of different areas of natural science and managed to amass a huge amount of evidence to back up his ideas. It's a tribute to his work that lots of that evidence stands the test of time today. What I find most impressive is that although he went about things in a very careful – almost narrow – way, his work ended up widening his viewpoint, rather than limiting it.

Talking of evolution, are there any new developments in this area of study?
The massive change in evolutionary biology is the advent of DNA sequencing: the ability to look at the actual thing that is changing and evolving – the information that is passed on from generation to generation. Being able to examine that like you might examine computer code allows us to do all sorts of things we never dreamed possible before: it gives us an incredible set of clues to the evolutionary past.

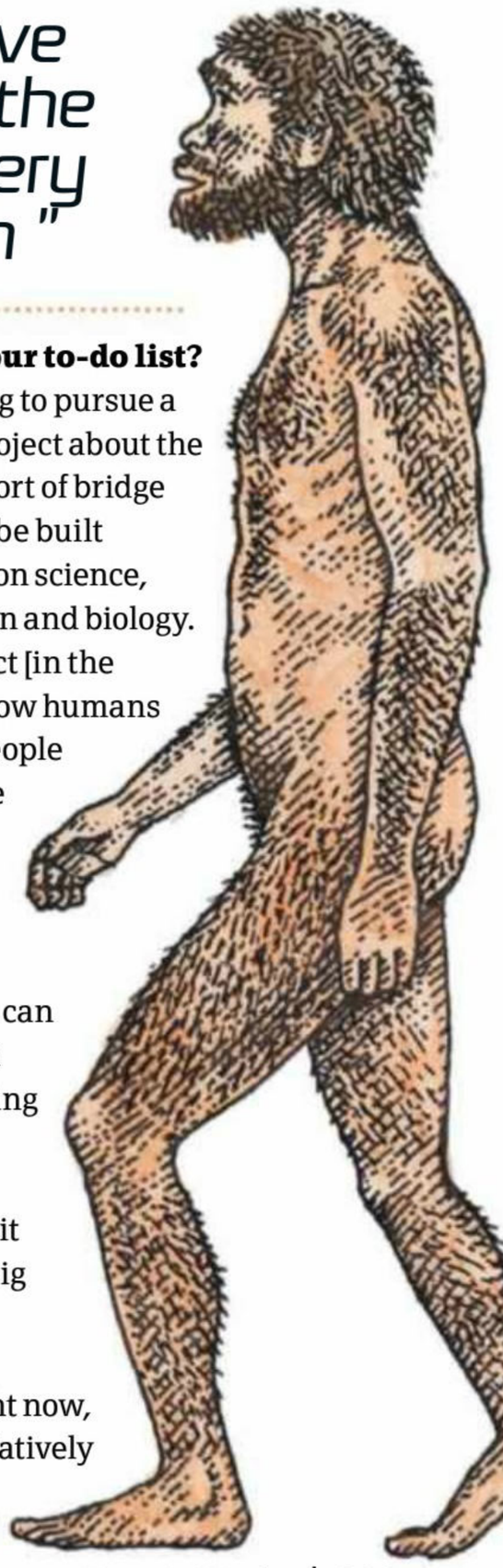
> *" Darwin was a very inquisitive and rounded biologist, but at the same time comes over as a very enlightened and humble man "*

After working with Richard Dawkins on *The Ancestor's Tale*, would you like to write another book by yourself?
Well, *The Ancestor's Tale* was an entire history of life and that gave me a rather wide view of biology. I feel it filled in a lot of the stuff that wasn't covered in my university course. Writing the book was a long slog, but I get on very well with Richard Dawkins and I'm glad I did it.

I suppose it would be nice to write something myself. I think I have a good overview of lots of areas of science, particularly in biology, and that might be helpful when writing a popular science book. On the other hand, you could accuse me of being a jack-of-all-trades and master of none! I think if you have a burning desire to write about a particular subject, then turning your thoughts into a book might be a good idea. I have some burning interests, but I'm not sure they would all make good books!

What's next on your to-do list?
Currently, I'm trying to pursue a computer-based project about the origin of life. It's a sort of bridge that I think should be built between information science, chemistry, evolution and biology. I've also got a project [in the works] to do with how humans dance, and what people watching the dance read into it.

And finally, with the advent of huge databases of DNA sequences that you can start analysing and mining for interesting evolutionary information, I'm dabbling in that a bit too because I'm [a big fan of] statistical analysis and visualisations. Right now, though, it is still relatively early days.



10 COOL THINGS WE LEARNED THIS MONTH

FACTS YOU ALL SHOULD KNOW

Dolphins are on the US Navy's payroll

Since the Sixties the US Navy has been training dolphins to use their keen eyesight and sophisticated sonar to search for objects, like mines, hidden under the sea. Their echolocation ability is much more sensitive than any man-made equipment, and in May 2013 two dolphins – called Ten and Spetz – discovered a rare 19th-century torpedo off the coast of California.

Honeybees trained for bomb disposal

Croatia is littered with land mines left over from the Balkan Wars, which ended in 1995. Since then, 316 people have been killed, but scientists have developed an ingenious solution. Honeybees have been trained to associate the smell of their sugary food with the smell of TNT. The plan is to release swarms of bees across de-mined fields and watch with infrared cameras; the trained bees will gather on any undetected mines without setting them off.

Lab-made burger is ready to eat

Dr Mark Post from the Netherlands is bringing his cultured meat to London in June to be tasted. The burgers are made from 20,000 strips of muscle tissue, grown using cattle stem cells. A single burger costs £210,000 ($325,000) to make and, although it lacks the fat of regular meat, it is meant to taste quite like the real thing.

Astronaut chow could be printed

3D food printers, like the one pictured from Fab@Home, could help to feed space explorers on their way to Mars. NASA has funded a research corporation to develop a 3D printer that can make hot food for space missions. So far, the team has printed out noodles, bread, cake and even turkey loaf, using food powders sterilised with UV light.

Smelly flower blooms in Eden

Titan arum, or the 'corpse flower', has a distinctive odour, described as a mixture of bad eggs and rotting flesh. It is the largest flower in the world and takes up to ten years to grow. This month the Eden Project in Cornwall, UK, was lucky enough to witness the rare and unusual plant in full bloom. Luckily the stench was short-lived as the flower dies after just 48 hours.

Graphene contains infinite butterflies

Hofstadter's butterfly is a complicated fractal pattern of energy made up of infinitely smaller and smaller butterflies. For 40 years this phenomenon of quantum mechanics was just theoretical, but using the two-dimensional carbon lattice graphene scientists have been able to directly observe this repeating pattern of electron energy for the first time.

Changing face of Earth can be seen in seconds

The NASA and US Geological Survey Landsat programme has used eight satellites to collect images of our planet over the last 25 years. Google has collected the best and created a public-access video that charts the ever-changing face of Earth. Searchable by location, it shows the recent history of the whole world, from the expansion of Las Vegas across the desert to the destruction of the Amazon rainforest.

Driverless cars are getting cheaper

Self-driving cars, like the one being developed by Google, use high-resolution 3D radar to navigate, but it costs upwards of £50,000 ($75,000). A teenager from Romania has developed an alternative using artificial intelligence (AI) webcam technology, which costs just £2,600 ($4,000). It uses lower-resolution 3D radar to identify large obstacles, while the webcam and AI recognise smaller objects.

Bugs can help us beat world hunger

The United Nations is urging people to eat more insects. Creepy-crawlies are high in protein and minerals like calcium and iron, and in some parts of the world they are considered a delicacy. They reproduce rapidly and farming them creates far less greenhouse gas emissions than conventional livestock like cattle and pigs, making them a real contender for sustainable food production.

Apple's tech is up to scratch

Apple has been granted a patent for technology which enables the casing of its devices to tell the difference between touching, thumping and scratching. Acoustic sensors will be able to hear your touch, allowing for an array of commands. In the future we may switch a phone to 'silent' just by tapping it with a fingernail.

Space planes

Discover how this new generation of aircraft will help us venture into space like never before...

Getting into space is no mean feat. Since the dawn of the Space Age we have relied on large, expensive and at times dangerous launch vehicles – namely rockets – to give payloads the necessary altitude and speed to get off our planet. Rockets use a huge amount of fuel, they're not reusable (hence their expense) and, perhaps most importantly, they have been known to fail with often disastrous consequences. But what if there was another way to travel off our world?

The holy grail of space exploration has long been to design some sort of vehicle that can launch from the ground, journey into space and return to Earth in one piece, with no expendable components and minimal risk. Space planes are one such idea that have been touted (and partially tested, as we'll explain later). They are vehicles that can take off from runways, travel into space and return to Earth. As their name would suggest they are essentially aeroplanes, but with a key difference: they are capable of operating both in the forgiving atmosphere of Earth and in the much harsher environment of space.

The first space plane of sorts was the rocket-powered X-15 jet in the Sixties. It remains the fastest manned vehicle ever launched and performed what is known as a suborbital flight, where a vehicle reaches the boundary of space and returns to Earth but does not enter orbit. Only two of the multitude of flights it performed technically reached space, but it lent weight to the concept of a space plane nonetheless.

Since then we have seen a few other pretenders take to the skies. NASA's Space Shuttle was a space plane in the sense that it glided back to Earth after completing operations in orbit, but as it launched on top of a rocket it was never regarded as a true space plane. The Soviet-built Buran spacecraft performed in much the same manner.

Now, in the coming years, we can expect to see more genuine space planes, each with a different design. The vehicle that has garnered the most attention in recent years has been ▶

SpaceShipTwo

Virgin Galactic's eight-seater SpaceShipTwo space plane will take off from Virgin's own Spaceport America in New Mexico. It will be carried by a larger mothership – WhiteKnightTwo – before detaching in the upper atmosphere and using a rocket motor to propel itself into orbit. It will be used initially for space tourism, with 400 passengers already paid up, and will begin flights in late-2013/early-2014.

THE PIONEER

Lynx Mk 1

Unlike SpaceShipTwo, California-based XCOR's Lynx space plane lifts off and lands all by itself. Carrying one pilot and just one paying passenger, it can take off from a conventional runway, taking a steep climb of about 75 degrees before levelling out into suborbit and then returning to Earth. It too will begin flights later in 2013 or at the beginning of 2014.

THE CONTENDER

RECORD BREAKERS

PRIZE FLIGHT

$10MN

FIRST PRIVATE SPACEFLIGHT

In 2004, SpaceShipTwo's predecessor SpaceShipOne completed the first two-manned private spaceflights with pilots Brian Binnie and Mike Melvill, scooping the $10mn (£6.6mn) Ansari X Prize in the process.

DID YOU KNOW? *In the 1960s Pan Am opened registration for trips to the Moon in space planes, but they never materialised*

Spaceport vs airport

There are currently two major spaceports being built in the USA: the Mojave Air and Space Port in California and Spaceport America in New Mexico.

Spaceports must be able to support the added force associated with a space plane both at launch and landing. Thus, runways must be reinforced and also longer than conventional ones as space planes require a longer distance to accelerate and brake.

Spaceports also need training facilities to prepare their passengers for the rigours of spaceflight. Like rocket launch sites, spaceports benefit from being placed near the equator too. This allows the aircraft to get an added boost from the rotation of the Earth, making it slightly easier (and so less costly) to reach orbit than if they were launching farther away from the equator.

Spaceport America in New Mexico, USA, is where Virgin Galactic's SpaceShipTwo will be based

Dream Chaser

Sierra Nevada Corporation's Dream Chaser will launch on top of a rocket (probably an Atlas V) into orbit. It is expected to be able to dock with the ISS before gliding back to Earth, just like the Space Shuttle once did. It should make its maiden trip in 2015.

★ THE NEXT SHUTTLE

Skylon

UK-based Reaction Engines Limited's Skylon plane could be a game-changer. It's intended to launch from a reinforced runway and return to Earth in a single unit and could carry 24 passengers. Development is ongoing and it may well be flying before the decade is out.

★ THE OUTSIDER

"It is expected that space-faring aircraft will be used to take cargo into orbit in the not-too-distant future"

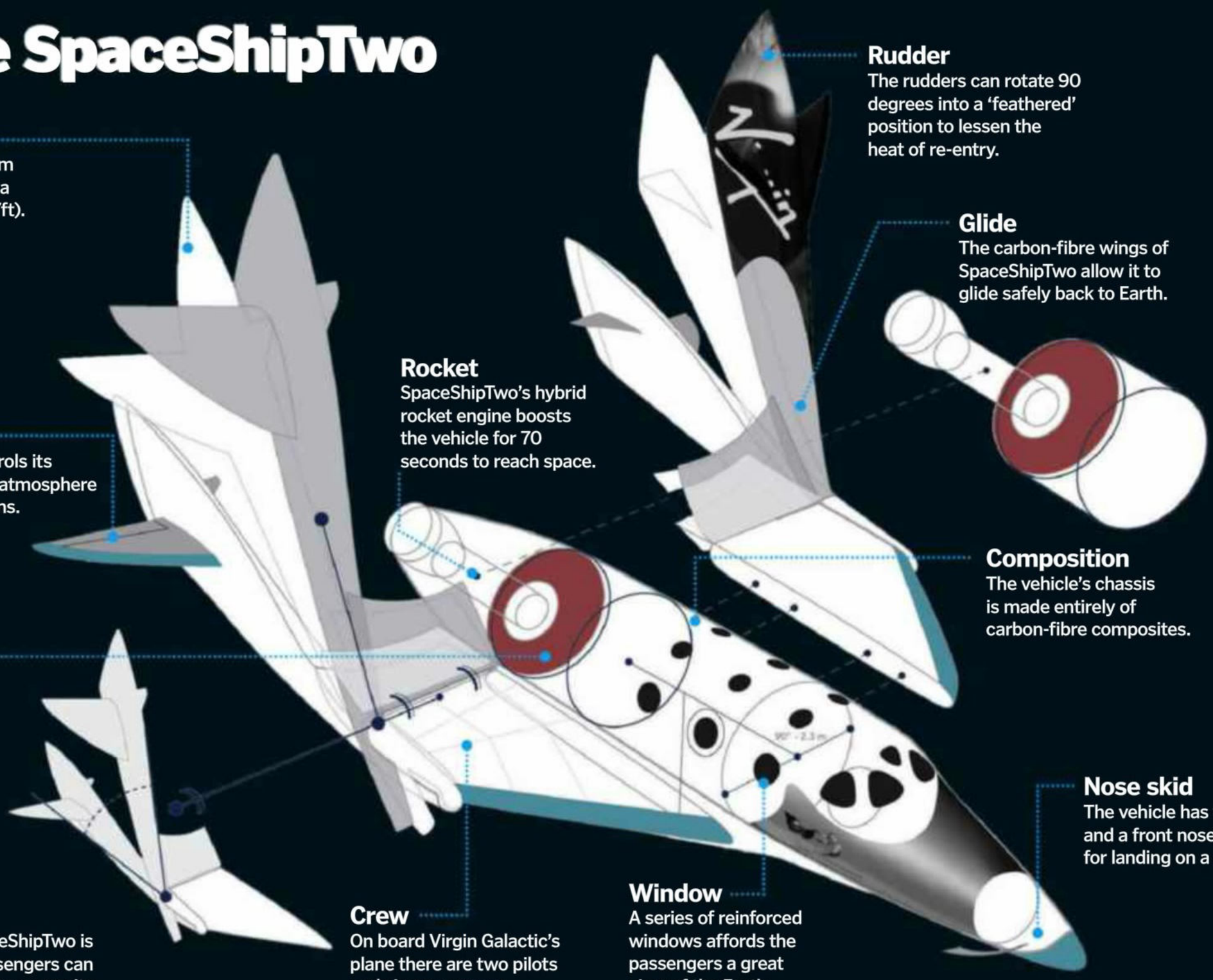
Virgin Galactic's SpaceShipTwo. This rocket-powered aeroplane is lifted into the sky by a larger mothership, WhiteKnightTwo, before separating and using its rocket engine to take six paying customers into space. Here, at a cost of $200,000 (£133,000) each – although this has recently risen to $250,000 (£166,000) – they experience six minutes of weightlessness.

It's not the only space plane in development though. A company called XCOR Aerospace has been quietly building its own vehicle, known as the Lynx aircraft, which will be able to take paying passengers into space. Unlike SpaceShipTwo it doesn't have a carrier vessel, and thus will be able to launch and land itself on a runway, bringing us a big step closer to the true vision of a space plane.

But aside from taking tourists on out-of-this-world trips, space planes have another more important use. It is expected, specifically with future versions of SpaceShipTwo and Lynx (eg SpaceShipThree and Lynx Mk 2), that they will eventually be able to launch payloads such as satellites into orbit. To do so they will reach their peak altitude before releasing a smaller spacecraft, which carries the payload into orbit. This would be a huge advancement for satellite operators, who at the moment must rely on rockets to get satellites off Earth but, in future, they could use aircraft at a much lower cost.

Space planes are also expected to fly passengers and crew not only into suborbit, but into full orbits around the Earth. One company hoping to do this is Sierra Nevada Corporation (SNC) with its Dream Chaser craft. With funding from NASA, they are hoping to launch this plane as the successor to the Space Shuttle. Travelling atop an Atlas V rocket, it will be capable of taking up to seven people into low Earth orbit

Inside SpaceShipTwo



Dimensions
SpaceShipTwo is 18m (60ft) long and has a wingspan of 8m (27ft).

Rudder
The rudders can rotate 90 degrees into a 'feathered' position to lessen the heat of re-entry.

Glide
The carbon-fibre wings of SpaceShipTwo allow it to glide safely back to Earth.

Rocket
SpaceShipTwo's hybrid rocket engine boosts the vehicle for 70 seconds to reach space.

Elevon
SpaceShipTwo controls its pitch and roll in the atmosphere with movable elevons.

Composition
The vehicle's chassis is made entirely of carbon-fibre composites.

Nose skid
The vehicle has wheels and a front nose 'skid' for landing on a runway.

Cabin
The interior of SpaceShipTwo is pressurised, so passengers can enjoy space without spacesuits.

Crew
On board Virgin Galactic's plane there are two pilots and six passengers.

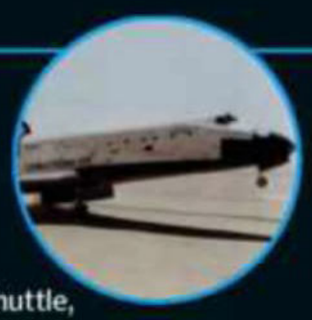
Window
A series of reinforced windows affords the passengers a great view of the Earth.

History of space planes

How It Works picks out a few key dates in the evolution of space-faring vehicles

1959
The first rocket-powered plane, the North American X-15, makes its maiden flight.

1963
Pilot Joseph Walker takes the X-15 into space, making it the world's first space plane.



1981
The Space Shuttle, capable of taking a crew and cargo to and from orbit, launches for the first time.

1988
The Soviet-built Buran space shuttle makes its first and only flight into space.

AMAZING VIDEO!

SCAN THE QR CODE FOR A QUICK LINK

The first rocket-powered flight of SpaceShipTwo

www.howitworksdaily.com

DID YOU KNOW? *Rolls-Royce and British Aerospace studied a space plane concept called HOTOL back in the Eighties*

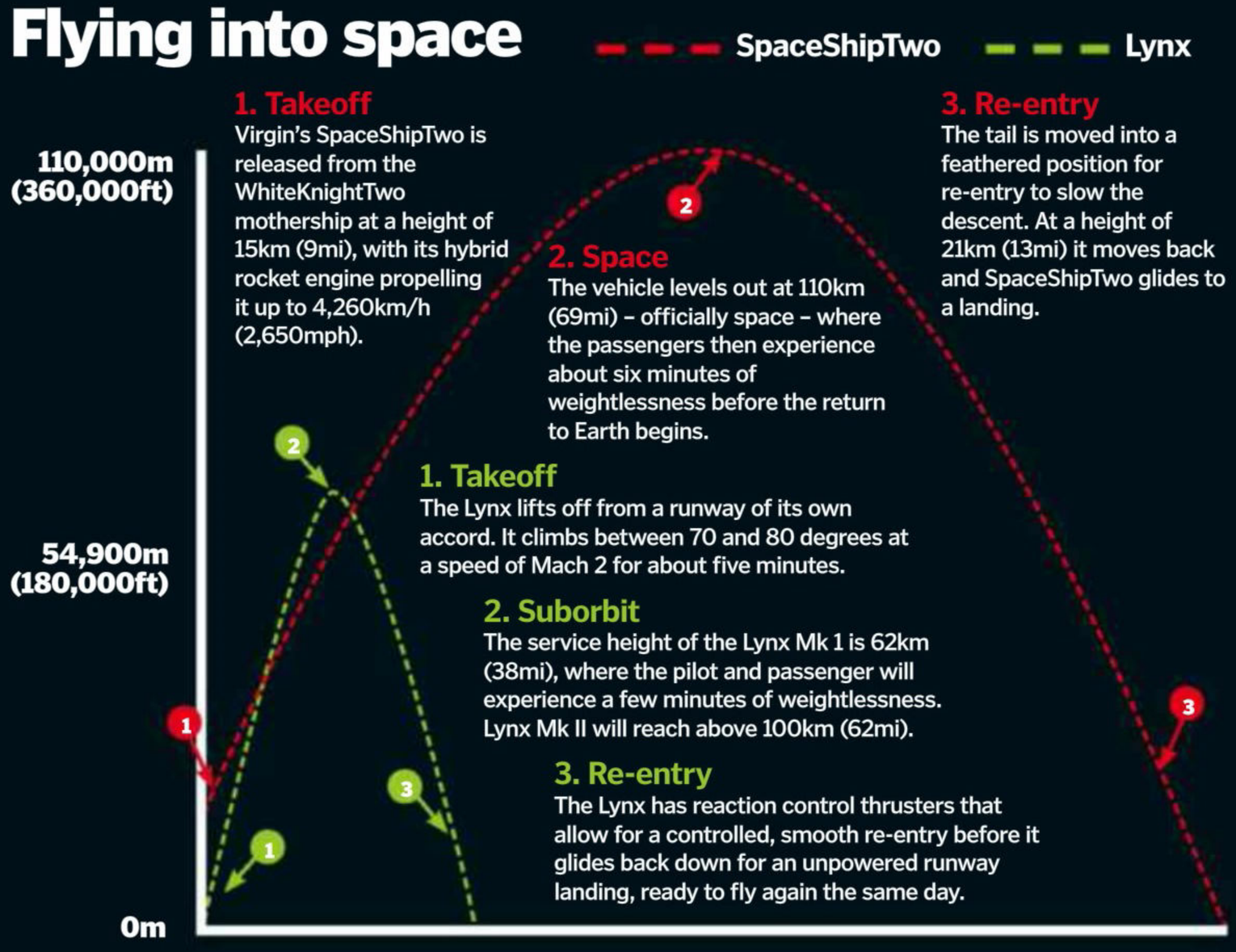
(LEO) where they could dock with the International Space Station (ISS). This would provide the ISS with another means of transporting crews to the station aside from Russia's Soyuz spacecraft. After leaving the ISS, the Dream Chaser will fly back down to Earth much like a regular aeroplane.

Another vehicle designed to take both people and cargo into orbit – but which is further behind in its development than the Dream Chaser – is the Skylon space plane. Currently being developed by UK-based Reaction Engines Limited (REL), Skylon could be a revolution in space travel if it ever flies, as it is larger than SpaceShipTwo and boasts a much bigger hold.

REL has stated that when Skylon lifts off – hopefully at some point towards the end of this decade – it will reduce the cost of taking a payload into space from £15,000 ($23,000) to just £650 ($990) per kilogram. It could also transport as many as 24 people off our planet at a time. The vehicle will use a hybrid air-breathing rocket engine to reach orbit in a single stage before gliding back to the surface.

The goal of space planes is, ultimately, to reduce the cost of going to space. While the early flights of SpaceShipTwo and Lynx will predominantly be centred around tourism, it is fully expected that space-faring aircraft will be used to take useful cargo into orbit in the not-too-distant future. Making space more accessible will enable us to operate more efficiently in Earth orbit, while the tourism aspect will help to fund those endeavours. Indeed, companies like Virgin Galactic have said that, while the first few hundred tourist flights will be quite expensive, future tickets should become much more affordable.

Flying into space



2004
Scaled Composites' space plane completes the first privately funded human spaceflight.

2005
Richard Branson's Virgin Galactic acquires Scaled Composites and then begins work on SpaceShipTwo.

2008
XCOR Aerospace announces that it will begin development of the Lynx space plane.

2013
SpaceShipTwo makes its first rocket-powered flight, a key step to full launches.

Steve Isakowitz

The Executive Vice President and Chief Technology Officer at Virgin Galactic tells us why we should be excited about space planes

Why are space planes important?
Space travel is one of the only transportation modes where we throw everything away every time we fly. What we're trying to achieve is the ability to fly these suborbital flights, bring down the [space plane], turn it around quickly and re-fly it over and over again.

Will tickets to space become cheaper?
That is our goal, to open up the space frontier for anybody who has the desire to go there. Once we prove this second-generation vehicle [SpaceShipOne was the first] we expect to have a third, fourth and fifth generation that will continue to drive down costs and improve reliability.

What differentiates SpaceShipTwo from the Lynx?
We're giving people the opportunity to unbuckle from their seats and have the opportunity to float within the cabin and experience both the euphoria of zero-g and looking out the windows and seeing an incredible view of Earth.

What can we expect in the future?
One of the things we keep our eyes on is point-to-point travel, the idea of flying between two very distant cities but at a fraction of the time that it takes a commercial airline to do it. You might be able to fly from Tokyo to Los Angeles in a third of the time that an airline currently does. That could be a huge industry that one could tap into [sometime in this decade] with some of the very technologies that we're trying to develop.

"Arthur C Clarke pointed out how geostationary satellites could bounce radio signals around the globe"

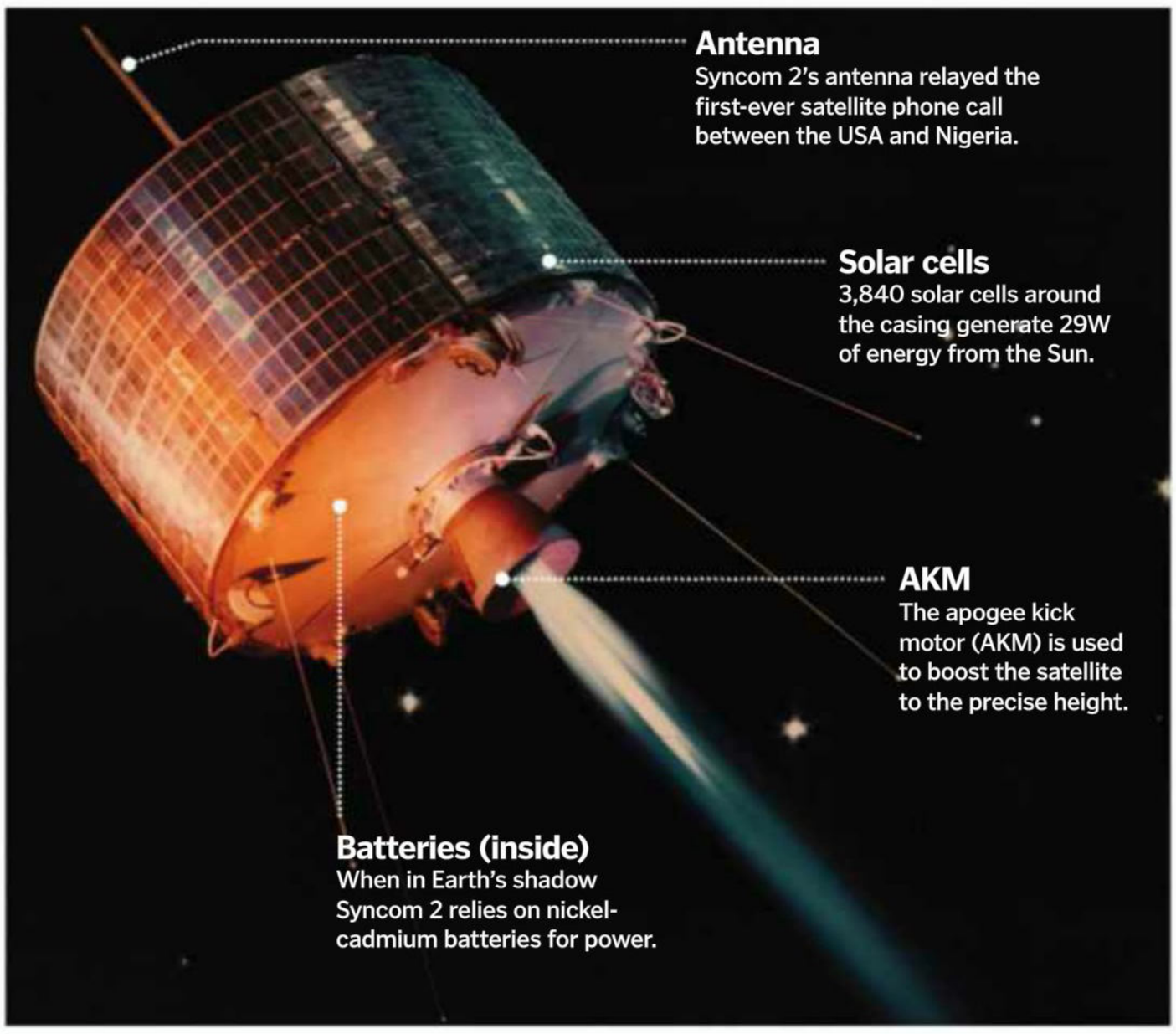
Geosynchronous satellites

These high-up satellites manage to keep pace with Earth's daily rotation and can even remain above exactly the same spot, but how do they work?

If a satellite orbits Earth at an average altitude of 35,786 kilometres (22,236 miles) above sea level, it will complete an orbit every 23 hours, 56 minutes and four seconds – exactly the same time that the planet itself takes to rotate. Satellites whose orbital periods match Earth's rotation are said to be 'geosynchronous'. Their orbits are often used to make sure a satellite is permanently visible from a particular point on the surface (like a transmitter), or that the satellite keeps a constant watch over a certain area.

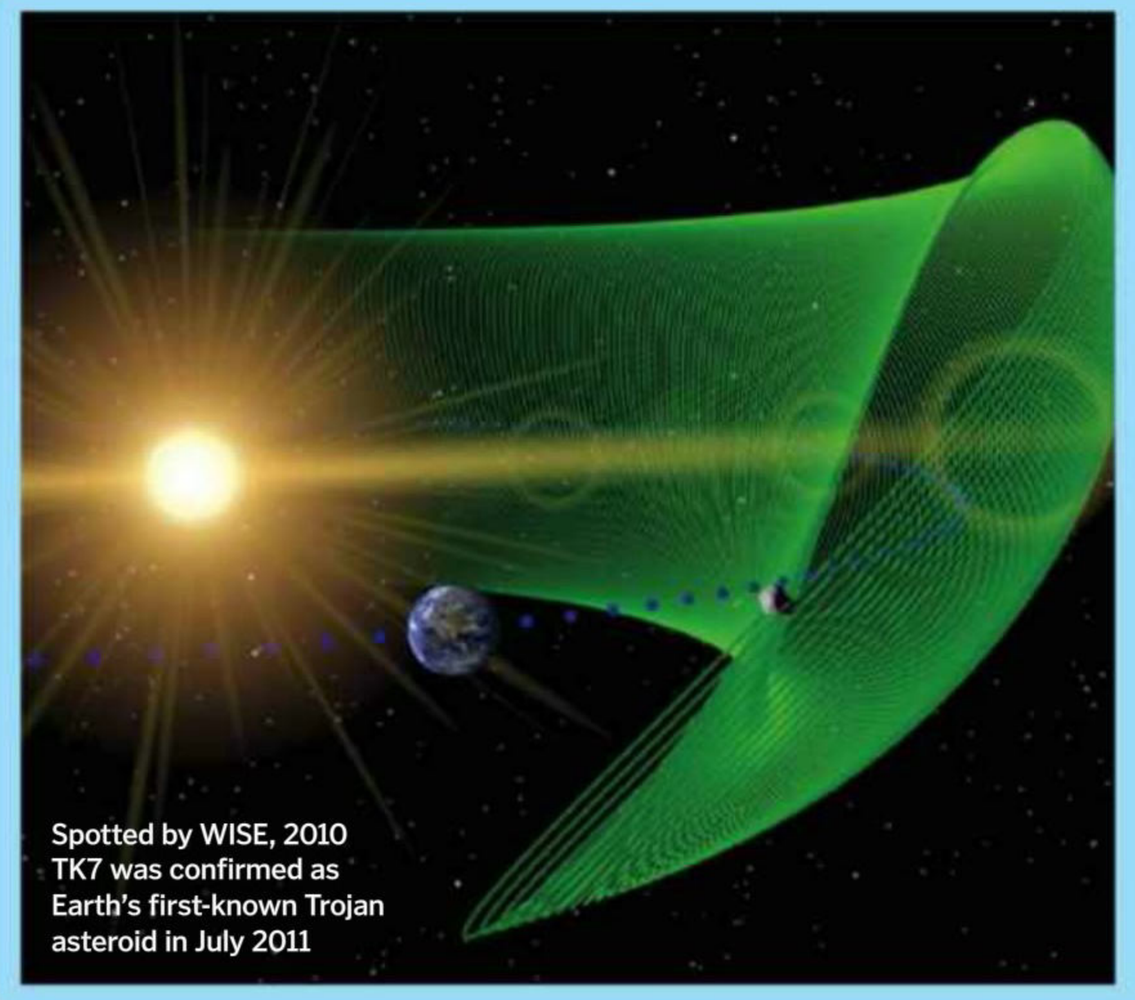
A special kind of geosynchronous orbit is a circular orbit above Earth's equator – in this case a satellite remains above exactly the same spot on the surface, and travels in the same direction in the sky. Austrian rocket engineer Herman Potočnik discovered this 'geostationary' orbit in 1928, but surprisingly it was science-fiction author Arthur C Clarke who, in 1945, first pointed out how geostationary satellites could be used to bounce radio signals around the globe.

The first geosynchronous satellite, the Boeing-built Syncom 2 (pictured), finally reached orbit in 1963, and the first truly geostationary satellite, Syncom 3, followed in 1964. Today, over 200 satellites hover in geosynchronous orbits; they are mostly used for communications (eg satellite TV and telephony), though sometimes also for weather observation and reconnaissance.



Trojan asteroids

Get to know the unusual space rocks that share the orbits of larger celestial bodies, but wisely keep their distance...


Spotted by WISE, 2010 TK7 was confirmed as Earth's first-known Trojan asteroid in July 2011

Asteroids are the debris of the Solar System – small chunks of rock that never came together to form larger planets. Today, they mostly orbit in the Asteroid Belt between Mars and Jupiter, though some occasionally fall into the inner Solar System and may become near-Earth objects (NEOs).

But there's another class of asteroids – the Trojans – that dice with death by sharing Jupiter's own orbit. They do this by clustering together in swarms that lie 60 degrees ahead of, and 60 degrees behind, the giant planet itself, occupying 'sweet spots' called Trojan points, or Lagrange points, where the gravitational pulls of the Sun and Jupiter are balanced.

In fact, the Trojans orbit the centre of mass, or barycentre, of the Jupiter-Sun system (which is well inside the Sun). Jovian Trojans were first spotted in the early-1900s, but in recent years we have found Neptune, Uranus, Mars and even Earth have Trojan asteroids of their own.

"Practical solar cells only became a reality thanks to the development of new semiconductors such as silicon"

Solar-powered spacecraft

Harnessing energy from the Sun, solar-powered space probes like Juno are taking environmentally friendly technology farther than ever before...

When you're launching a space probe to a distant planet, every kilogram counts. Every aspect of the design is a compromise between weight and scientific capability. With engine fuel at a premium, and batteries heavy and limited in life, solar cells – which draw their energy from the Sun itself – are an ideal way of generating power.

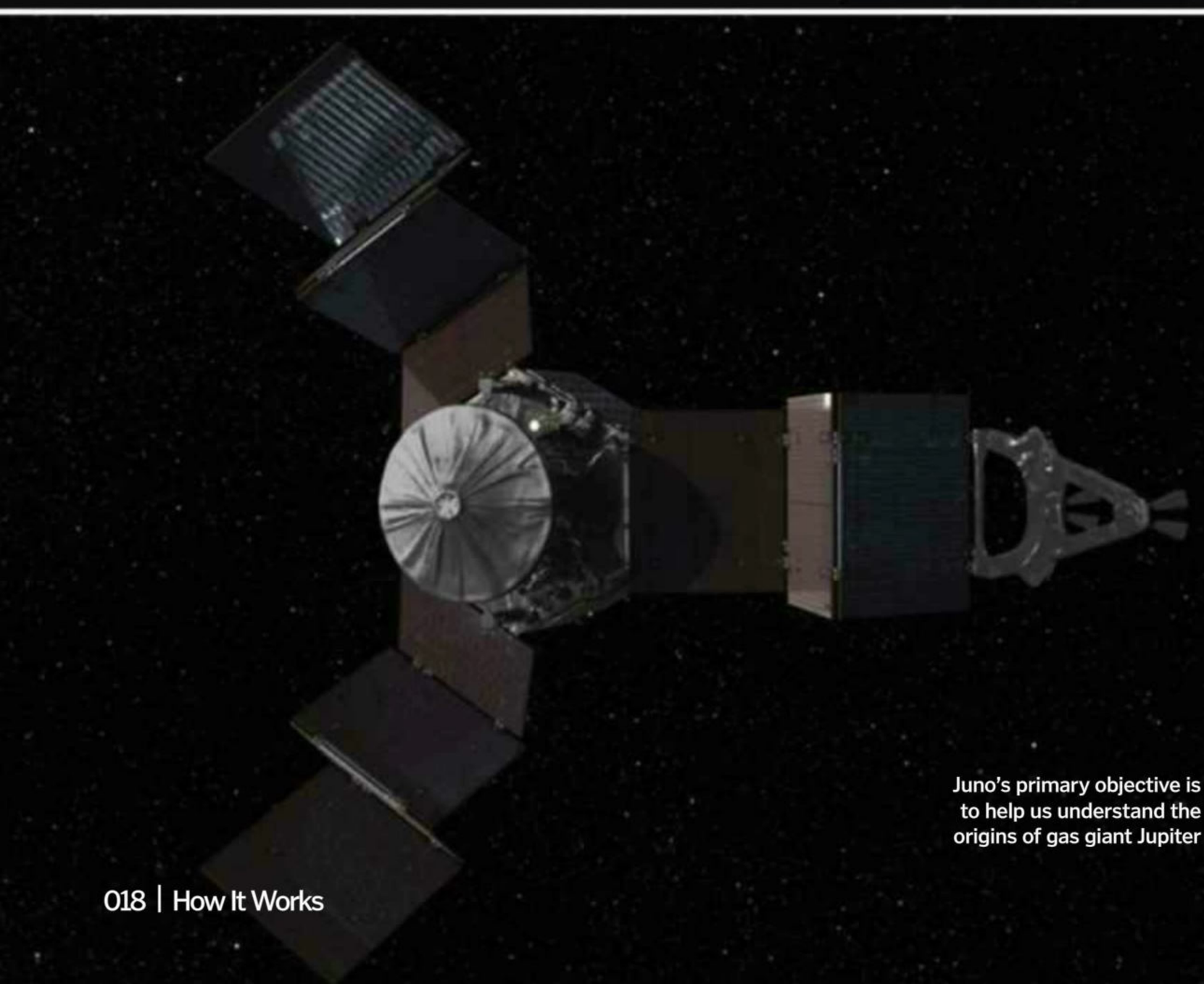
Solar cells rely on the photoelectric effect, which causes current to flow through certain materials when they are struck by light. The effect was discovered as early as the mid-1800s, and explained by Albert Einstein in 1905. It arises when individual photons of light striking a surface provide enough energy for charge-carrying subatomic electrons to break free of their individual atoms.

However, practical solar cells only became a reality thanks to the development of new semiconductor materials such as silicon and gallium arsenide in the mid-Fifties – just in time for them to be used in some of the earliest Earth satellites, and later in space probes.

For more far-flung missions, however, there's a stumbling block: the energy available from sunlight drops proportionally with distance from the star. As a result, solar energy has until recently only been a viable power source for missions to the inner Solar System (ie as far out as Mars). Advances in the efficiency of solar cells, along with the ability to pack and unfurl larger arrays (each carrying many separate cells) are starting to change that, as ably demonstrated by the Juno mission to Jupiter.

While most spacecraft still use solar cells purely for powering on-board systems, an increasing number are using them for propulsion too. Solar-electric, or 'ion engine', propulsion uses sunlight to split propellant into electrically charged ions and fire them out of the engine at extremely high speeds. The acceleration force this produces is tiny, but can be sustained for months or even years with just a small fuel supply. This makes it perfect for use on complex missions such as the Dawn probe currently touring the Asteroid Belt.

Coming online
Directly after launch, Juno only needed the power from two of its solar array panels; the others are needed as it travels farther from the Sun.



Juno's primary objective is to help us understand the origins of gas giant Jupiter

Harvesting solar power at Jupiter

Launched in August 2011 and scheduled to arrive at Jupiter in 2016, NASA's Juno mission will push solar power technology to its limits in order to give us a unique new view of the largest planet in the Solar System. Previous probes to the outer Solar System, such as the Voyager missions and the Cassini orbiter, had to carry a radioactive power source with them, but advances in solar cell design – specifically the use of highly efficient multi-junction photoelectric materials made from crystals of gallium arsenide – will enable Juno to operate despite receiving just four per cent of the sunlight available at Earth.

Three huge solar arrays will generate 486 watts of power, roughly half of which will be used to keep the spacecraft warm, while the other half powers Juno's flight systems and scientific instruments. Juno's orbit will carry it high above Jupiter's poles, and as it will spend long periods of time in the gas giant's shadow, the power will also be used to charge a pair of lithium-ion batteries that should keep the spacecraft operating while it's in the dark.

KEY DATES

SOLAR POWER

1958
The US launches Vanguard 1 (right), a grapefruit-sized satellite and the first to be powered by the Sun.

1970
The Soviet Union's Lunokhod 1 is the first solar-powered rover to land on the Moon.

1998
NASA's Deep Space 1 mission (right) pioneers solar-electric propulsion, paving the way for missions like the Dawn probe.

2010
JAXA's IKAROS spacecraft launches and successfully uses a solar sail as its main means of propulsion.

2011
Juno launches – the first spacecraft to use solar power in the outer Solar System.

DID YOU KNOW? *The solar cells on Vanguard 1 powered a transmitter that kept sending signals to Earth for almost seven years*

Unfurling Juno's wings

This artist's impression captures the moment Juno deployed its enormous solar arrays, just 54 minutes after launch...

Solar cells
The solar arrays carry a total of more than 18,000 individual cells and could generate around 15kW of power in Earth orbit.

Twin arrays
Two of Juno's solar arrays are 8.9m (29ft) long and 2.7m (8.9ft) wide, each consisting of four separate panels.

Rotation
Juno spins on its central axis roughly once every two minutes, with the distribution of the solar arrays helping it to remain stable.

Communications
Stabilised by Juno's slow spin, the high-gain antenna will keep a lock on Earth throughout the mission, allowing radio communication.

The statistics...

Juno spacecraft

Launch: 5 August 2011

Launch mass: 3,625kg (7,992lb)

Scheduled Jupiter arrival: July 2016

Number of Jupiter orbits: 33

Planned orbit altitude: 5,000km (3,100mi)

Key instruments: UV imager/spectrometer; plasma detector; radio/plasma wave experiment; six-wavelength microwave radiometer

Ready for radiation
All Juno's electrical components, including the solar cells, are specially designed to operate in the harsh 'radiation belts' around Jupiter. Nevertheless, the components are still expected to fail after 15 or so months.

Smaller array
Juno's third array has just three panels, with the place of the fourth taken by a magnetometer for studying Jupiter's magnetic field.

"Wavelengths shorter than visible light allow us to observe the most energetic objects in space"

Observing deep space

We discover how a handful of invisible wavelengths across the electromagnetic spectrum help us see deep into the universe

The Pinwheel Galaxy

Tracking emissions from different parts of the EM spectrum means we can shoot objects like this, 21 million light years away

Yellow
Visible light from stars, captured by the Hubble Space Telescope.

Purple
X-ray emissions from supernovas and high-speed collisions near black holes, captured by the Chandra X-ray Observatory.

Red
Infrared heat emitted by the dust where new stars are forming, captured by the Spitzer Space Telescope.

Blue
Ultraviolet light emitted by young stars, captured by the Galaxy Evolution Explorer (GALEX).

NASA: "It is like seeing with a regular camera, an ultraviolet camera, night-vision goggles and X-ray vision, all at the same time"

The human eye is amazing, but it can only detect a tiny percentage of the electromagnetic radiation emitted by the universe. However, using telescopes sensitive to other wavelengths, astronomers can build up detailed images of previously unseen cosmic phenomena.

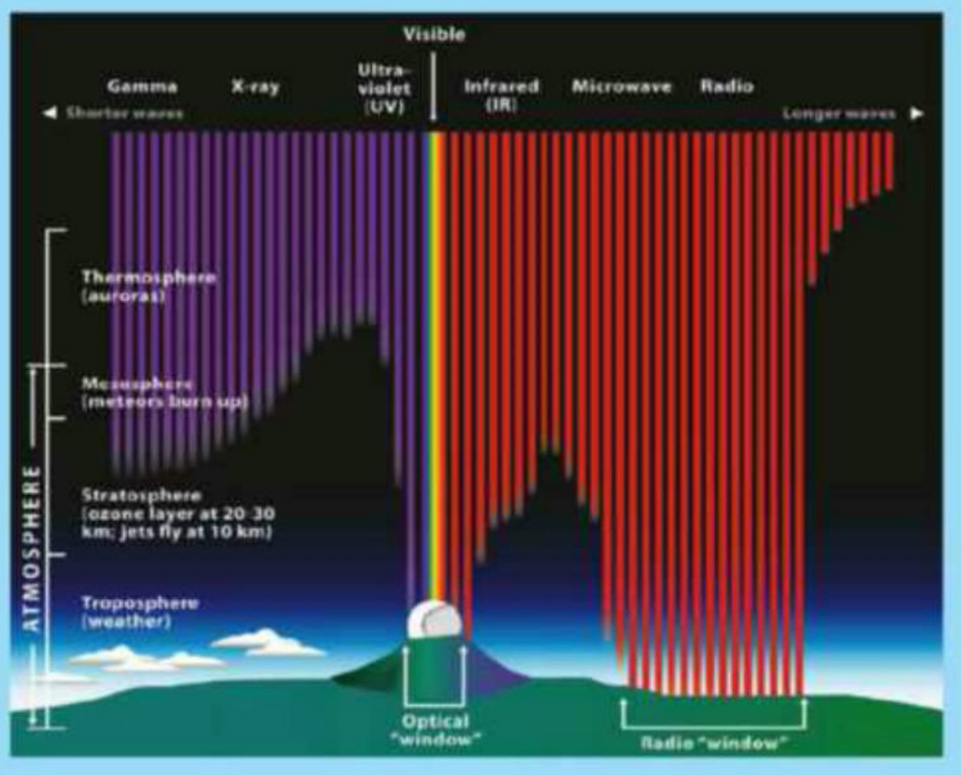
The longest waves in the electromagnetic spectrum are radio waves, microwaves and infrared (IR). Radio waves are emitted from supermassive black holes, supernova remnants and pulsars known as radio stars. Because radio waves are so long, they can pass easily through cosmic dust, revealing hidden areas of the universe. Similarly, IR light can travel through dust clouds without being diffracted, enabling us to study new stars from birth.

There is a low-energy, uniform background of microwaves across the universe, thought to be an artefact of the heat from the Big Bang. As the cosmos cooled and expanded the wavelengths were stretched and lengthened to the cold microwaves that can be observed today.

Wavelengths that are shorter than visible light allow us to observe the hottest and most energetic objects in space. Newly forming stars emit very bright ultraviolet light, which gradually fades as they age. This means astronomers can examine the evolution of galaxies. At even higher temperatures, X-ray and gamma-ray emissions can be observed, revealing very high-energy events like solar flares, supernovas and black holes.

When combined together the various electromagnetic emissions picked up from objects in space help scientists build up a comprehensive picture of the universe that is far more detailed than we could ever achieve relying on visible light alone.

What is the optical window?



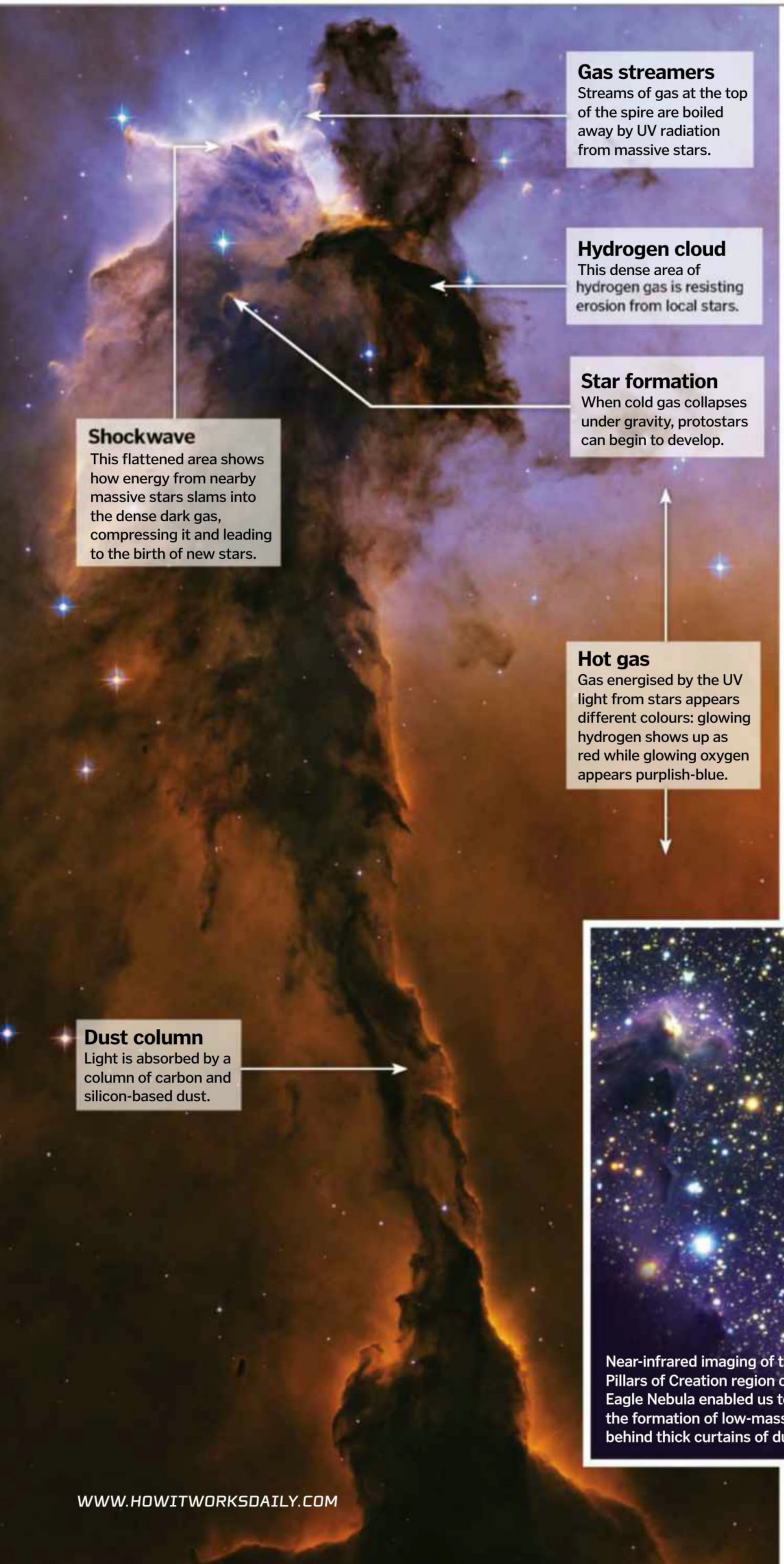
The Earth's atmosphere and magnetosphere efficiently block much of the electromagnetic radiation from space, protecting us, but making it difficult to detect non-visible wavelengths from the ground. Telescopes on Earth are only able to detect radio waves, visible light and some ultraviolet and infrared wavelengths (the optical window). Some IR telescopes are placed on mountaintops, but for experiments looking at other electromagnetic wavelengths the equipment must be taken into, or beyond, our planet's atmosphere. This can be done for minutes at a time with rockets, months at a time with balloons, or even for years with detectors mounted on satellites.

THE STATS
EAGLE IN SPACE

DISTANCE FROM SUN **7,000LY** | APPARENT MAGNITUDE **6** | FIRST DISCOVERED **1745-46**

DIAMETER **70LY** | AGE **5.5mn yrs** | LENGTH OF SPIRE **91.7tn km**

DID YOU KNOW? *Most of the light from the Eagle originates in the large M16 star cluster, which can be seen with binoculars*



The Eagle Nebula explored

What goes on inside this stellar nursery and what can it tell astronomers about the complex process of star formation?

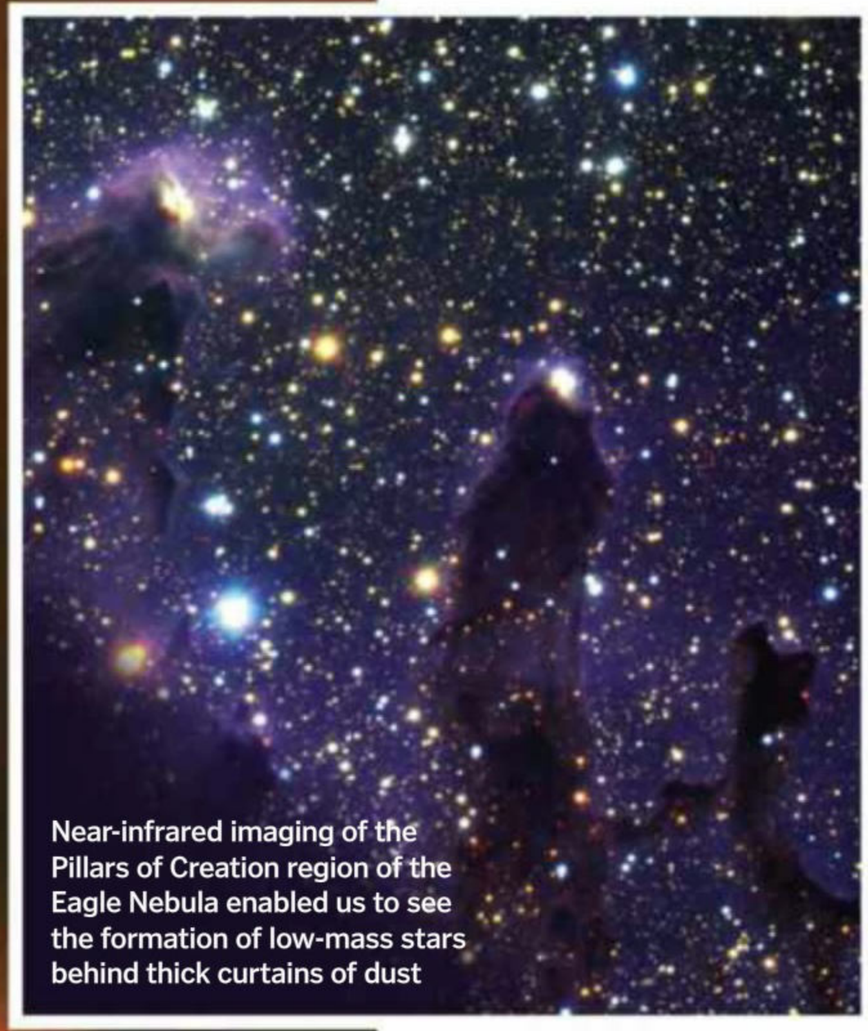
The Eagle Nebula is a star-forming region of the universe located within the dense Carina-Sagittarius spiral arm of the Milky Way. The towering 'Stellar Spire' column of ultra-cold dust and ionised gas which is pictured here represents just a tiny portion of the nebula. The dense gases and solid-but-minuscule particles inside nebulas are the major ingredients necessary for creating young stars. New stars form when clumps of this gassy, dusty matter collapse under gravity.

The Eagle Nebula would appear dark to us were it not for the intense light coming from nearby star clusters, which illuminate the interstellar matter from behind. The atoms of gas and dust in emission nebulas like this glow due to energy from local stars.

Stars don't just make nebulas easier to see; they also create some pretty unusual formations inside them. The star-making dust and gas of the Stellar Spire has been boiled away by the ultraviolet (UV) radiation emitted by stars formed in the nebula, leaving behind a dramatic sculpted pillar.

Within the main nebula a cavernous hollow has formed a protective shell around an open cluster of stars that continues to form and give out light energy. This cold wall of dust and gas is being pushed back by the UV radiation, boiling away the lower-density stellar material to leave behind the denser matter in the shape of tall towers with globules of dark dust and gas on their surfaces (see inset image).

The three Pillars of Creation, famously photographed by the Hubble telescope in 1995, are examples of such dust columns surrounded by glowing ionised gas. They are thought to be the birthplace of many stars.


Near-infrared imaging of the Pillars of Creation region of the Eagle Nebula enabled us to see the formation of low-mass stars behind thick curtains of dust

"If the stars are close enough together, their gravitational pull enables them to exchange matter"

Binary stars explained

How do multi-star systems form – and do planets exist where the sun sets twice?

It is estimated that a third of the stars in the Milky Way are part of a binary (two) or multiple (three upwards) star system, with more than one star orbiting a common centre of mass, or barycentre.

Depending on the mass of each star and the conditions of their formation, they can be quite close together or millions of miles apart, and the time it takes for them to orbit varies from hours to millennia. Binary star systems are particularly useful to astronomers because they can accurately determine the mass of the stars by analysing their orbits; this then enables them to estimate the mass of similarly bright lone stars.

Some binaries can be seen through a telescope, but many are only detected indirectly, either when one star eclipses another, or when the wavelengths of light emitted vary as the stars circle around their barycentre.

If the stars are close enough together, their gravitational pull enables them to exchange matter; this can be seen as a bright disc around the recipient star. If the recipient is a white dwarf, hydrogen received from its companion can be compressed by the intense gravity at the core and undergo nuclear fusion. This process releases huge amounts of energy, which can be seen as a nova. In some cases the energy can be so great that it triggers a supernova event, destroying the star.

Binary star systems can also drift apart, resulting in the formation of single stars. The breakup of multi-star systems can also occur due to close interaction with neighbouring celestial bodies, causing dramatic fluctuations in gravitational pull and leading to stars being thrown out of a system. These 'runaway stars' have been seen hurtling through space at speeds of up to 30 kilometres (18.5 miles) per second.

A planet with two sunsets

Around 200 light years away, Kepler-16b orbits two stars in the constellation of Cygnus – we explore the system now

Kepler-16A
The larger of the two stars is an orange dwarf, 69 per cent the mass of our Sun.

Kepler-16B
The smaller star is just 20 per cent the mass of our Sun and is a cooler red dwarf.

Kepler-16b
This planet is half-gas, half-rock and ice, with surface temperatures between -101 and -73°C (-150 and -94°F).

KEY DATES

DOUBLE ACTS

1650
The double stars Mizar and Acrux in Ursa Major are spotted by Giovanni Battista Riccioli.

1767
John Mitchell first suggests that double stars are not aligned by chance, but are physically attached.

1802
William Herschel first uses the term 'binary' to describe the idea that two stars might together make up a system.

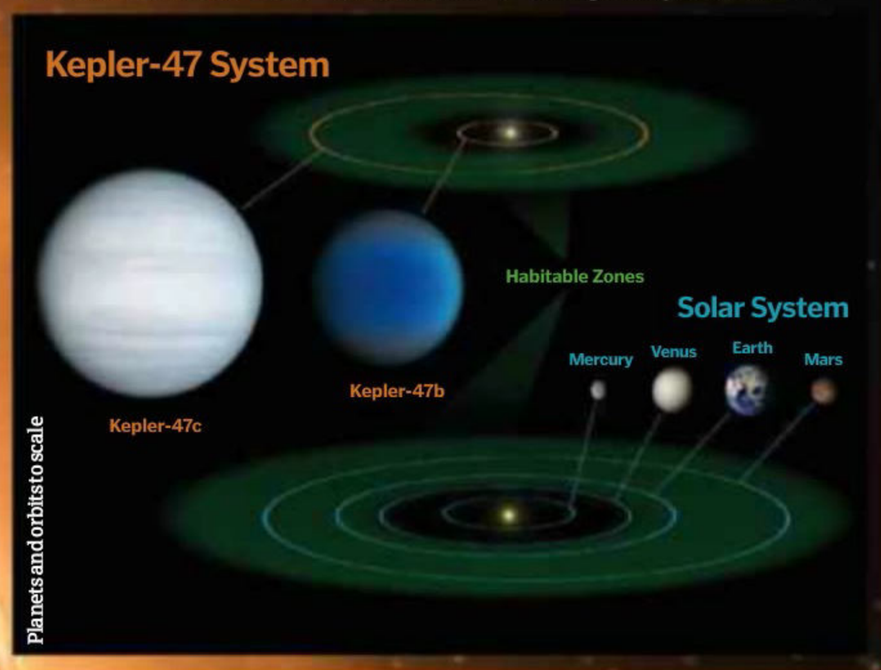
1977
Star Wars and the fictional planet Tatooine bring binary star systems to the public's attention.

2011
The first exoplanet with two stars, Kepler-16b, is discovered by NASA's Kepler space telescope.

DID YOU KNOW? *The discoverers of Kepler-16b informally call it 'Tatooine', in reference to the fictional planet from Star Wars*

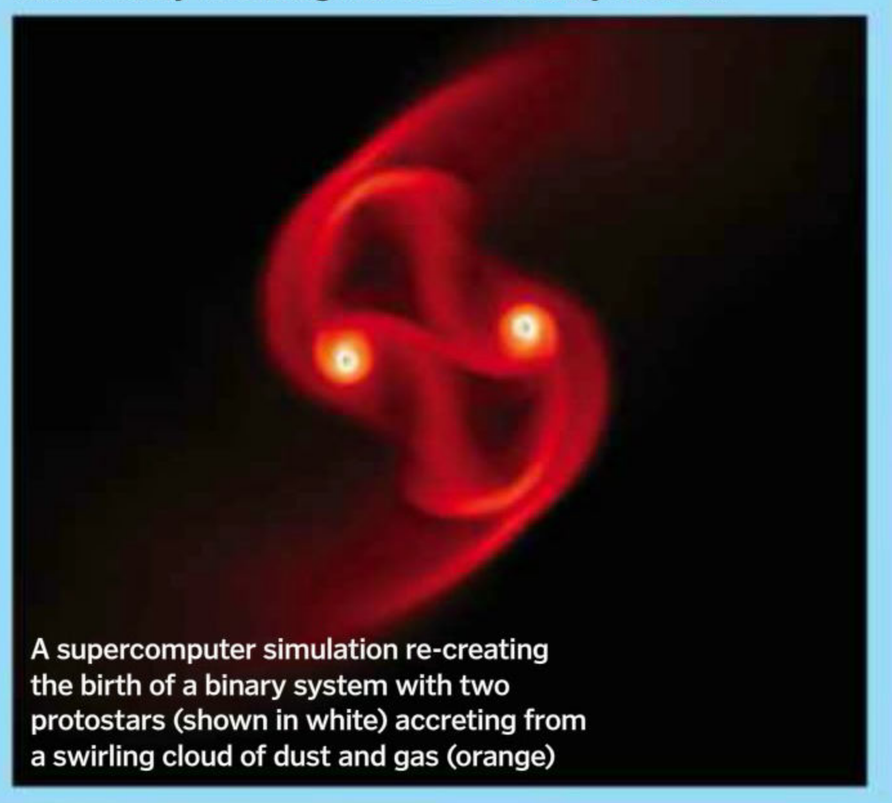
Living with two suns

Planets in binary star systems can orbit one, or both, of the stars. The surface temperature of some of these bodies varies wildly as the distance to the stars changes when they orbit, however it is now thought that binary star systems may be more likely to contain extraterrestrial life than single star systems like our own. For planets to be at the correct temperature for life in solitary star systems they have to be quite close to their star, which leaves them open to bombardment by solar winds and harmful radiation. However, if two low-mass stars are close together, planets farther out will be able to get enough heat without being subjected to so much damage. There are so many binary star systems that, if you subscribe to this theory, then the chances of finding planets in a habitable zone with similar environmental conditions to our own – and thus life – are greatly increased.



Double star origins

All stars are the product of dust and gas collapsing under gravitational force. As the collapse occurs, the material is not always uniformly distributed, creating areas of denser matter, which pull the dust into spinning discs, gradually incorporating it into two or more separate protostars. It is also possible for stars to 'capture' other stars as they pass each other in space, but their gravitational attraction is rarely strong enough. Capture is a viable option for the formation of multi-star systems, which have much greater combined gravitational pull, but currently it is thought to be a secondary method.



A supercomputer simulation re-creating the birth of a binary system with two protostars (shown in white) accreting from a swirling cloud of dust and gas (orange)

Eclipse
As the stars move in front of one another, the light intensity seen from Earth alters, allowing astronomers to calculate their distance and mass.


Komodo dragons taste the air to find their prey by flicking their tongues


Since the domestication of grey wolves thousands of years ago, selective breeding has made dogs more docile

The planet's deadliest animals

If you go down to the woods today... you may not come out alive!

We don't live in a dog-eat-dog world. It's much more dangerous than that. Dog eat dog suggests an evenly matched fight, but animals in the wild prefer to attack from a position of overwhelming superiority. A snake that has a taste for mice can inject enough venom to kill 125 mice with a single bite, while an animal that relies on physical strength will aim for an instant kill by crushing the skull or slicing the throat.

The prey is fighting for its life and will put up the maximum possible struggle, but the predator is only hunting for its dinner and cannot afford even minor injuries so it must strike hard and kill quickly.

Humans, however, are weak. Almost any animal our size could easily beat us in a fight. We protect ourselves by keeping away from most of nature and using technology to protect ourselves. Most of the time this works. But you can't spend your whole life in a shark cage and animals carry their weapons with them all the time. So when accidental wild encounters with do occur, the fight isn't likely to go our way.

There are lots of ways to rate the deadliness of an animal. The total number of human fatalities every year is one, but it doesn't take into account how rare the animal is, or where it lives. Brown bears kill more people than polar bears do, but that doesn't make brown bears more deadly per se. It just means that a lot more people go hiking in Alaska than on the sea ice in the Arctic Circle. Official statistics can be misleading too. Shark attack figures tend to exaggerate the deaths from the easily identified species, such as the great white and the tiger shark and those that feed close to the shore, where there are likely to be lots of witnesses. As you will see, the shark species probably responsible for the most human deaths has almost no confirmed kills to its name, precisely because it never leaves any witnesses...

Where an animal is venomous, rating the deadliness of its venom is very tricky. Venom toxicity is measured using the LD50 rating. This is the dose of venom, in milligrams per kilogram of body weight, required to kill 50 per cent of the mice in a sample. Mice are used because they are a convenient laboratory animal which can stand in for humans. But mice are also common prey for many snakes, scorpions and lizards and so have evolved a high degree of immunity to the venom of several species. The predator adapts to this by

3.4m

LARGEST EVER POLAR BEAR

In 1960 a polar bear was shot in Alaska that weighed over 1,000 kilograms (2,204 pounds)! Rearing up on its hind legs, it was almost twice the average height of a man at 3.4 metres (11.2 feet) tall!

DID YOU KNOW? *Mosquitoes can't transmit HIV; the virus is quickly digested and never gets injected back into a host*


The polar bear is the largest land carnivore and its great size means it can overpower even large prey


According to the International Shark Attack Files, records of shark attacks on humans go back to the 16th Century

injecting ever-larger amounts of venom and this makes them even more dangerous to humans. So paradoxically, animals with low venom toxicity as measured by LD50 in mice, can be among the most lethal to humans.

The list we have compiled here contains ten of the very deadliest animals on the planet, covering as wide a range of different habitats and kill tactics as possible. Inevitably, we have had to leave out some very worthy runners-up. The Nile crocodile eats about 320 people a year and tigers have killed 373,000 people since the beginning of the 19th century. The cape buffalo is an extraordinarily aggressive animal that has probably killed more hunters than any other animal in Africa. But our list is a representative sample of the meanest killers from across the whole of Mother Nature's realm.

"What makes dogs so deadly is that we take them for granted; always treat a hound with respect"

SEA WASP JELLYFISH

The sting king

- **Size** 30cm (11.8in) body, 3m (9.8ft) tentacles
- **Habitat** Open water • **Location** Australasia
- **Diet** Prawns, small fish • **Kill tactic** Sting

The sea wasp is the largest and most deadly of the Cubozoa, or box jellyfish. In fact, it may be the most venomous creature in the world. Sea wasps are predators, hunting small fish and shrimp, but their delicate bodies make it essential for them to immobilise their prey immediately. Their venom works on humans by causing red blood cells to leak potassium molecules, which disrupts the electrical signals that allow muscles to contract and so your heart stops beating. This works the same way as the lethal injection used for capital punishment.

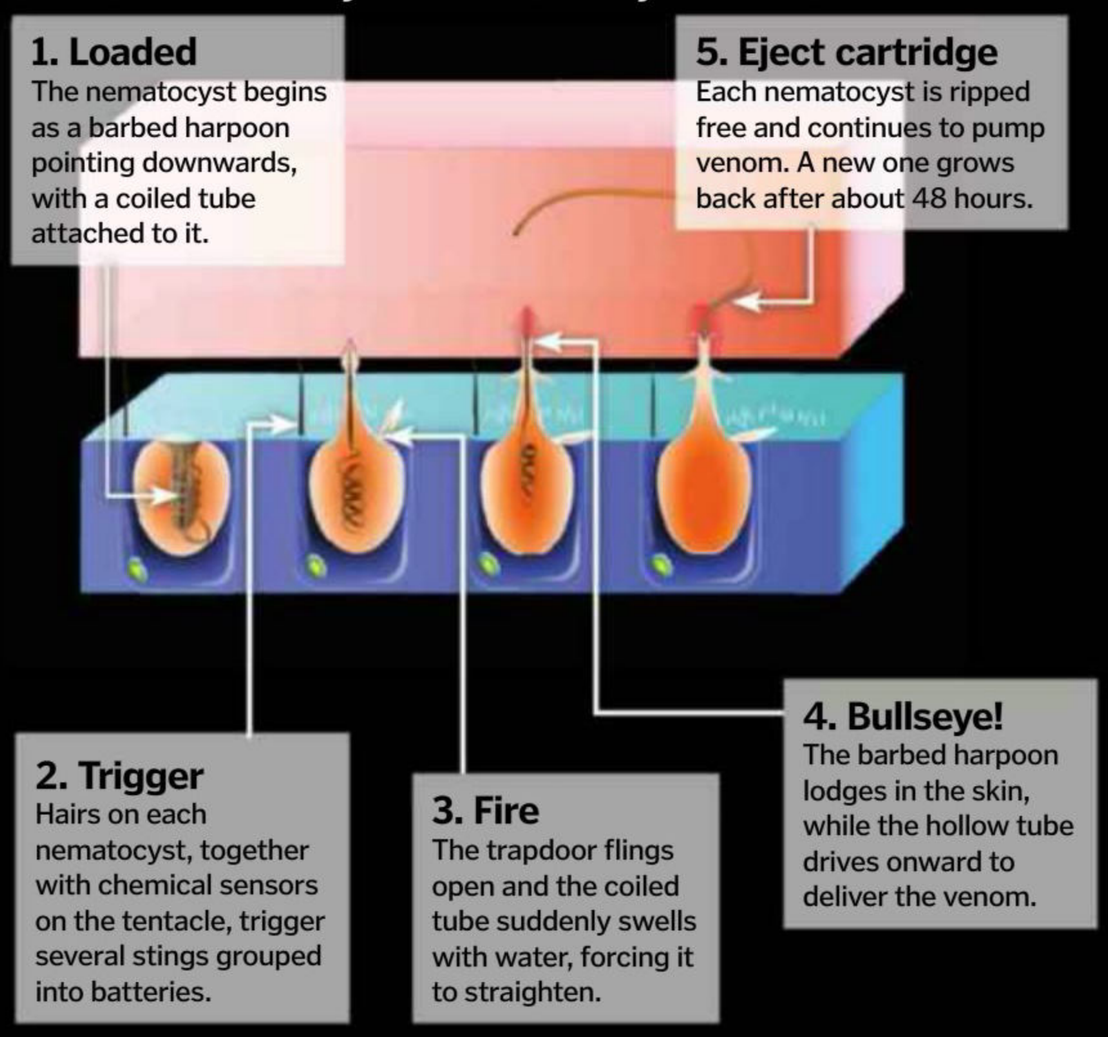
Sea wasps can gather in shallow coastal waters in large numbers at certain times of year and their bodies are virtually transparent, making it easy to blunder into one by accident. Victims often drown before reaching the shore, or die of heart failure soon after, even after receiving medical treatment.

STING STATS

- Average number of tentacles per sea wasp jellyfish: 60
- Number of stings per tentacle: 500,000
- Time to kill: 2-5 minutes
- Average number of humans killed each year: 40

Microscopic harpoons

Jellyfish tentacles are lined with batteries of stinging cells called nematocysts – see how they work now



ATTACK STATS

- Top speed on land: 40km/h (25mph)
- Bite strength: 350N
- Attack triggers: Territory encroachment, loud noises, prey behaviours
- Average number of humans killed each year: 100

Dogs kill at least 20 times more people than wolves do

DOG

Friend or foe?

- **Weight** 50kg (110lb) • **Habitat** Our homes • **Location** Worldwide
- **Diet** Commercial dog food • **Kill tactic** Bite to the throat

Dogs have lived alongside humans for 30,000 years. In that time our ancestors have used selective breeding to make them more docile and friendly than their wolf ancestors – or have they? Around 4.7 million people are bitten by dogs and 26 people killed each year in the US alone. Most of these attacks are from the 'Molosser' category of breeds, which includes the boxer, great dane and rottweiler. These are heavy dogs, once bred for guarding, hunting and attacking. The victims are mostly infants who have wandered into a neighbour's garden, babies in their prams and the elderly. Running or snatching your hand away can trigger a predator response that can quickly escalate. But what makes dogs so deadly is that we generally take them for granted; always treat a hound with respect.

SOUTHERN CASSOWARY

ATTACK STATS

- Top speed on land: 48km/h (30mph)
- Claw size: 12.5cm (4.9in)
- Jump height: 1.5m (4.9ft)
- Confirmed human fatalities: 1

The Queensland slasher

- **Height** 1.7m (4.9ft) • **Habitat** Tropical rainforest • **Location** Indonesia, Australasia
- **Diet** Fruit, insects, fungi • **Kill tactic** Kick/slash

The southern cassowary is the second heaviest bird on Earth, after the ostrich, and is also the only other bird known to have attacked and killed humans. Records of fatalities only exist for Queensland, Australia, and don't include attacks on natives in Indonesia and New Guinea. The southern cassowary is most distinctive for its bright blue neck and a bony crest on its head. The crest is sometimes used to butt victims as the bird charges, but most injuries are caused by its kick. The claw of each inner toe is like a paring knife and the cassowary can jump to chest height before slashing. Humans have had their throats cut by a single strike and the force of the kick alone is enough to cause internal bleeding.

DID YOU KNOW? *Pregnant polar bears will eat enough to more than double their body weight in just four months*

ANOPHELES MOSQUITO

The silent assassin

- **Length** 15mm (0.6in) • **Habitat** Stagnant water
- **Location** Sub-Saharan Africa, South America, India
- **Diet** Nectar, blood • **Kill tactic** Disease transmission

The mosquito Anopheles gambiae is 12,000 times smaller than a human. Inside its mouth is a protozoan organism that is 12,000 times smaller again. And yet, between them, they kill almost a million people a year worldwide by transmitting and causing malaria. Male mosquitoes eat plant nectar and are quite harmless. The female eats nectar too, but some species also bite mammals to supplement their diet with protein. Although many mosquito species are capable of becoming disease carriers, only a few live in close contact with us. Anopheles gambiae is particularly deadly because it breeds in any available standing water, lives for a long time and prefers to bite humans. The Plasmodium parasites that actually cause malaria enter the bloodstream along with the insect saliva and take just minutes to travel to the liver, where they begin to multiply. Malaria appears largely dormant as long as only the liver is infected, but every few weeks or months, the liver cells rupture to release a kind of spore cell that infects red blood cells. This causes fever, vomiting, seizures and anaemia, then the cycle repeats.

Wing
The insect's wings beat roughly 600 times a minute, producing that distinct whining sound.

Abdomen
Can hold up to three times the mosquito's weight in blood. It takes three days to digest.

Salivary glands
Glands inject an anti-clotting agent into the blood, along with the malaria parasite that lives inside the salivary glands.

Antenna
It's the smell of CO_2 and octenol from our skin that explains why some people are bitten more than others.

Eye
Mosquitoes use their keen eyesight to locate suitable hosts and to choose their target area.

Mandibles and maxillae
These pierce the skin with a sawing action, driving the proboscis deeper and deeper until it strikes a blood vessel.

BITE STATS

- **Duration of average bite** 60 seconds
- **Amount of blood drawn in a bite** 3.75mg
- **Incubation period** 10-28 days
- **Average number of humans killed by malaria each year** 930,000

POLAR BEAR

Ice-cold killer

- **Weight** 550kg (1,213lb) • **Habitat** Sea ice
- **Location** Arctic Circle • **Diet** Ringed seals, bearded seals • **Kill tactic** Skull-crushing bite

An adult male polar bear can rear up over 2.1 metres (seven feet) on its hind legs and weighs twice as much as a silverback gorilla. He can outrun you and outswim you and a swipe from his paw or a bite from his jaws will be the last thing you see. In the wild, polar bears wait next to holes in the sea ice and, when they smell the breath of a seal, they haul it out of the water with one paw and crush its skull with a single bite. Polar bears have been observed taking on one-ton walruses that have metre-long tusks and even beluga whales. Adult polar bears get most of their energy from the fat in blubber and seldom eat land animals. The rare attacks on humans mostly occur in autumn when sea ice is all but gone so they can't catch seals.

ATTACK STATS

- **Top speed on land** 40km/h (25mph)
- **Bite strength** 1,650N
- **Food consumption** 46 seals/year
- **Average number of humans killed each year** <1

Polar bears can swim up to 322km (200mi) from land

"Komodo dragons normally attack from ambush, but can run at 19km/h (12mph) and even climb trees"

BLACK MAMBA

Fatal fangs

• **Length** 3m (9.8ft) • **Habitat** Savannah, woodland and farmland • **Location** Central and eastern Africa • **Diet** Rats, bush babies, chickens, other snakes • **Kill tactic** Venom

The black mamba is Africa's longest venomous snake. It generally keeps away from humans and is responsible for far fewer snakebite cases than the cobra, viper or krait, but it is very aggressive and has the fastest-acting venom of any serpent. Without antivenom, a bite is invariably lethal to humans. Since the venom spreads so quickly in the body, victims can die within 20 minutes. The black mamba can rear up high and often attacks the body or even the head, striking several times. The venom causes dizziness, paralysis, acute abdominal pain and heart failure. Even if the victim is treated with antivenom, paralysis can be permanent.

One strike and you're out!

Don't let the tiny teeth fool you – this snake packs an incredibly nasty bite

Short fang
A black mamba has short fangs which do not fold flat inside the mouth.

Black mouth
The black mamba is named for the black inside of its mouth, which it gapes to scare off large animals.

Jaw muscles
Black mambas will bite and release large prey, but mice and rats are gripped firmly until they are dead.

Venom gland
Each bite injects about nine times the lethal dose of venom for humans and they can bite up to 12 times!

Neck muscles
The black mamba can raise the front third of its body off the ground when moving, allowing for powerful forward lunges.

BITE STATS

- Amount of venom injected: 100mg
- Fang length: 5mm (0.02in)
- Time to kill: 20 minutes
- Average number of humans killed each year: 1,000 (estimated)

You're more likely to be bitten by a male Sydney funnel-web

SYDNEY FUNNEL-WEB

The venomous villain

• **Size** 4cm (1.6in) • **Habitat** Under rocks and logs • **Location** Within 100km (62mi) of Sydney, Australia • **Diet** Insects, frogs, lizards • **Kill tactic** Venom

The female Sydney funnel-web spider spends most of her time in a burrow, monitoring the trip wires from her funnel-shaped web. The male, on the other hand, wanders out in warm weather, looking for females. This means you are most likely to be bitten by a male, which is a problem because its venom is six times more powerful than the female's. Sydney funnel-webs are super-aggressive and won't flee if challenged. Instead they will bite multiple times to inject as much venom as possible. The venom contains atracotoxin, which causes muscle twitching, low blood pressure and respiratory failure. Most mammals have a high immunity to Sydney funnel-web venom, but humans are acutely sensitive. The relatively low number of deaths is due to the spider's limited distribution and because a very effective antivenom exists.

BITE STATS

- Fang length: 6mm (0.2in)
- Amount of venom injected: 1.7mg
- Time to kill: 28 minutes
- Confirmed human fatalities: 14

KOMODO DRAGON

An ambush predator

• **Length** 3m (9.8ft) • **Habitat** Open grassland and forest • **Location** Indonesia • **Diet** Deer, carrion • **Kill tactic** Bite

There are very few confirmed attacks on humans by Komodo dragons, and even fewer fatalities, but this is mainly because they are very rare. There are fewer than 5,000 in the wild, spread across five remote islands in Indonesia. Komodo dragons are determined predators that normally attack from ambush, but can run at 19 kilometres (12 miles) per hour and even climb trees to reach prey. Their jaws have a bite force that is actually less than a domestic cat's, so they don't kill by crushing. Instead they will hold down prey with their heavy forelimbs and slice chunks out of their victim with incredibly sharp teeth. Komodo teeth also have a layer of living tissue covering them that gets torn as they feed. The mixture of blood, saliva and carrion in their mouths creates a breeding ground for a range of toxic bacteria and, even if prey makes a getaway, bite wounds are very likely to become septic. Komodo dragons also have venom glands that can inhibit blood clotting and induce muscle paralysis.

ATTACK STATS

- Smell range: 9.5km (5.9mi)
- Bite strength: 70N
- Food consumption: 12 meals per year
- Confirmed human fatalities: 2 in 40 years

Komodos force large prey down their throat by ramming against a tree!

What kills the most people each year?

A Sharks B Bees C Coconuts

Answer:
The myth that falling coconuts kill more people than sharks is based on a single, widely misquoted research paper. Bee-stings, on the other hand, kill 53 people a year in the United States alone – far more than sharks and coconuts combined.

DID YOU KNOW? *Black mamba venom is at least 20 times more potent than the venom of the European adder*

HIPPOPOTAMUS

The big mouth

• **Length** 4.5m (14.8ft) • **Habitat** Savannah and forest riverbanks • **Location** Sub-Saharan Africa • **Diet** Grass • **Kill tactic** Bite

The hippopotamus has long had the reputation of Africa's most dangerous animal. Although it only eats grass, the hippo is extremely short-tempered. Their massive canine tusks are razor sharp, half a metre (1.6 feet) long and used purely as weapons. Hippos can open their mouths wider than any other land animal; there are even tales of luckless hunters having their head and shoulders bitten clean off! These animals are very territorial in the water, with males defending their harem and females protecting their calves. Boats are overturned without provocation and the tipped-out occupants often killed. On land hippos aren't so territorial, but will still attack safari tours in their vehicles, as well as lions and crocodiles. Fatal attacks have declined in recent years, but only because the hippo itself is growing rarer.

The hippo has the widest mouth on land and equally huge canines ideal for fighting

ATTACK STATS

- **Size of mouth gape** 150° (humans can only open 45°)
- **Bite strength** 8,100N
- **Length of tusk/tooth** 50cm (19.7in)
- **Average number of humans killed each year** 150 (estimated)

OCEANIC WHITETIP SHARK

Deep-sea destroyer

• **Length** 3m (9.8ft) • **Habitat** Deep waters warmer than 18°C (64°F) • **Location** Tropical seas • **Diet** Squid, fish • **Kill tactic** Bite, feeding frenzy transmission

According to the International Shark Attack File, there are only seven recorded unprovoked attacks on humans by oceanic whitetip sharks. The great white shark has 139 unprovoked attacks to its name since 1990, with 29 of them fatal. But what elevates the oceanic whitetip shark to the ranks of the truly deadly is the number of attacks that go unrecorded. This is a deep-water species that rarely comes into contact with swimmers or surfers, but it is believed to be responsible for a large number of deaths among shipwreck victims. In particular, during World War II, the USS Indianapolis and the troop ship Nova Scotia were both torpedoed by submarines in tropical waters. Hundreds of the initial survivors are thought to have been eaten by oceanic whitetip sharks in both cases.

BITE STATS

- **Swim speed** Slow
- **Bite size** 20cm (7.9in) diameter
- **Number of teeth** 54-60
- **Average number of humans killed each year** Unrecorded

Whitetips may have once been the most abundant large predators

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DID YOU KNOW? *The word plankton derives from the Greek term for wandering*

How amber forms

Learn how this beautiful gemstone develops, sometimes freezing tiny critters in time

Amber is tree resin that fossilises over millions of years. During the process, the resin loses many of its volatile properties and – placed under intense pressure and temperatures – transforms into a solid, orange-coloured gemstone.

As tree resin starts off in a sticky, viscous state, today many amber deposits feature ancient life forms, like insects and reptiles, or plant foliage – most dating between 30-60 million years old. These organic inclusions are highly prized, both by palaeontologists – who can study long-extinct organisms – and jewellery makers.

Currently, the oldest discovered amber dates from the Upper Carboniferous period, roughly 320 million years ago. This age is rare, however, and the majority of resin extracted dates from the Early Cretaceous or later. Most amber found today is thought to stem from the Sciadopityaceae family of conifer trees that were once prolific throughout Europe.

Plankton under the microscope

A critical part of the marine food chain, plankton come in all shapes and sizes

'Plankton' is a catchall name for a diverse group of marine or freshwater organisms that are so small and/or weak that they can't swim against a current. Indeed, this inability alone is what classifies an organism as planktonic, with bacteria, algae, molluscs, crustaceans and more all falling under this label.

Despite their minuscule size, plankton species number in the hundreds of thousands and are a critical component of food chains. Fish and marine mammals – including those as massive as whales – feed extensively on plankton (some exclusively) and without them many ecosystems in the ocean would simply collapse.

Plankton are subdivided according to size, with those larger than 20 millimetres (0.8 inches) – such as jellyfish – referred to as megaplankton, while at the other end of the scale, organisms less than 0.2 micrometres – such as marine viruses – are known as femtoplankton. In between these two extremes there are several other categories, containing a wide array of organisms ranging from cephalopoda (like octopus hatchlings) through to flagellates.

Planktonic organisms

Copepod

Feeding on even smaller microscopic plants and animals than themselves, copepods are parasitic organisms and a key constituent of plankton. They are found in all of Earth's oceans, and there are about 13,000 described species.

Rotifer

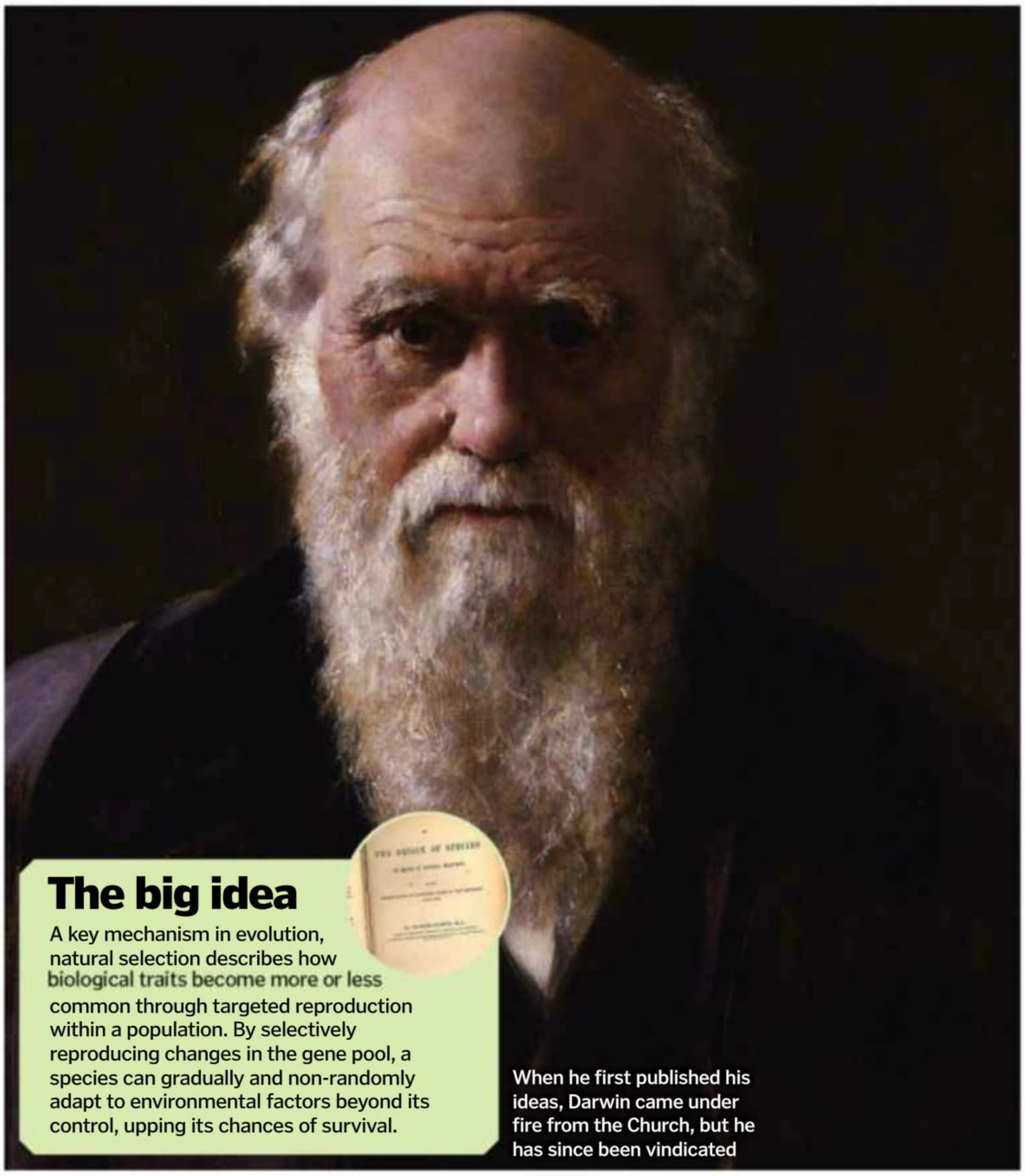
Measuring just 0.1-0.5 millimetres (0.004-0.02 inches) in length, rotifers have to be one of the most weird-looking members of the plankton family. Interestingly, despite their tiny size, they are related to nematodes, or roundworms.

Diatom

There are over 100,000 species of diatom, which are photosynthetic, single-celled algae. They play an important role in the base of marine food chains and are a common type of phytoplankton (micro plants).

Charles Darwin

The father of evolutionary biology, Darwin is the most famous naturalist of the Victorian era, if not all time



The big idea

A key mechanism in evolution, natural selection describes how biological traits become more or less common through targeted reproduction within a population. By selectively reproducing changes in the gene pool, a species can gradually and non-randomly adapt to environmental factors beyond its control, upping its chances of survival.

When he first published his ideas, Darwin came under fire from the Church, but he has since been vindicated

Charles Robert Darwin was an English naturalist renowned today for his theories of evolution and natural selection, both of which were introduced in his seminal work *On The Origin Of Species*.

The book was both lambasted and celebrated on its publication, by various groups. The early controversy stemmed from its apparent undermining of much religious scripture, but it would become one of the most influential works of Western society, with the entire field of evolutionary studies arising from it.

Though *On The Origin Of Species* was published in 1859, Darwin originally conceived of evolution by natural selection shortly after an around-the-world tour starting in 1831. He embarked on the journey to expand his newly formed interest in natural history, spending the trip collecting specimens and analysing many interesting species, when not suffering from seasickness. During the expedition on HMS Beagle he collected over 5,436 skins, bones and carcasses of various creatures. His experiences and findings led him to question many of the accepted beliefs concerning life's origins.

In 1838 he pinned down his theory of natural selection proper – see 'The big idea' boxout for more details. Over the next 20 years, he continued to refine it until he received a letter from fellow British naturalist Alfred Russel Wallace proposing a collaboration. The fact that both men shared the same ideas led to the joint publication of their research. While Wallace's hypotheses on the subject were detailed, his hands-on research was lacking and Darwin's extensive fieldwork won out, with history since attributing the theory largely to the latter.

A life's work

Famous for describing the evolution of humanity, we chart Darwin's own evolution through the 19th century

1809
Charles Darwin is born in Shrewsbury, England. His parents are Robert (above) and Susannah Darwin.

1818
In June, Darwin goes to Shrewsbury School as a boarder, where he studies for seven years.

1825
Darwin signs up for medical courses at the University of Edinburgh with elder brother Erasmus.

1827
He is admitted to Christ's College Cambridge to study not science but divinity.

1831
Accepts an offer to join a voyage on HMS Beagle which sets sail on 27 December.

"The publication of On The Origin Of Species was a landmark moment for Darwin – and for science"

Although some claim the significance of Galápagos finches to Darwin's theories has been overblown, more recent research indicates they are a good example of micro-evolution

In their footsteps...

Joseph Hooker

Sir Joseph Dalton Hooker was one of Darwin's closest friends and classified the plants he collected in the Galápagos Islands. Hooker also played a key role in the formulation of Darwin's theory of natural selection, offering critical feedback during the drafting process. Hooker was the first recognised man of science to support his radical ideas.

Richard Dawkins

British evolutionary biologist Richard Dawkins holds Charles Darwin as one of his major influences. Since reading Darwin's work at university, Dawkins has forged a career in biology that has seen him publish numerous acclaimed titles including *The Greatest Show On Earth*, which claims to lay down concrete evidence for evolution.

The publication of *On The Origin Of Species* the following year was therefore a landmark moment for Darwin – and for science as a whole. To a degree it was a bringing together of various ideas that had already been mooted by other biologists but unproved. While Darwin did not supply concrete evidence for evolution, the work's lucidity and logic meant that, towards the end of the 1870s, the scientific community, and society as a whole, had accepted his views.

Darwin followed up this groundbreaking title in 1871 with *The Descent Of Man, And Selection In Relation To Sex*, where he applied his own evolutionary theory specifically to human's evolution from apes. This book was incredibly popular from the word go, with a reprint ordered within just three weeks of publication. Three months after its release, 4,500 copies had been sold – a testament to his rising fame.

Darwin died on 19 April 1882 from heart disease and, after a request by his colleagues, was granted a state funeral at Westminster Abbey, buried alongside other famous scientists John Herschel and Isaac Newton.

The HMS Beagle spent just five weeks in the Galápagos Islands, but that was long enough for Darwin's research purposes

Perhaps the most famous resident of the Galápagos, the giant tortoise

Top 5 facts: Charles Darwin

1 Family guy
Darwin had ten children, though two died while still young. Three of his sons went on to become members of the Royal Society themselves.

2 On the money
Darwin is commemorated in the UK with his portrait printed on £10 banknotes, alongside a hummingbird and the ship HMS Beagle.

3 School of thought
The school that Charles Darwin attended as a boy, Shrewsbury School, still exists, but it is no longer in the same building, which has since become a library.

4 Name gets around
Due to Darwin's great achievements in the field of natural history, more than 120 species and nine different genera have been named in his honour to date.

5 No sea-lover
HMS Beagle took five years to circumnavigate the globe, but Darwin only spent 18 months on board. From the day it set sail, he was afflicted with terrible seasickness.

1836
Lands back in England on 2 October and returns home to Shrewsbury.

1839
Marries Emma Wedgwood and has his first of ten children.

1858
Receives a letter from Alfred Russel Wallace who shares many of his ideas about the theory of natural selection.

1859
Publishes *On The Origin Of Species By Means Of Natural Selection, Or The Preservation Of Favoured Races In The Struggle For Life*.

1864
Receives the Copley Medal, the highest accolade from Britain's Royal Society.

1882
Darwin dies, aged 73, and is buried at Westminster.

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DID YOU KNOW? *Hydrogen peroxide is also a common agent used in rocket fuel!*

Bombardier beetle self-defence

What explosive technique does this scavenging insect use to protect itself when under attack?

Bombardier beetles have a unique means of self-defence, seeing off predators by blasting them with a disorientating caustic jet of steam and liquid. A violent explosion erupts from the rear end of the insect when two chemicals are combined and then catalysed.

The concentrated substances are secreted from glands into a reservoir where they are mixed inside the creature's abdomen. When the beetle feels threatened a muscular valve then forces the concoction into a second chamber. Here a catalyst causes an exothermic reaction that raises the temperature of the liquid to boiling point.

It is then ejected under great pressure out the tip of the insect's abdomen. This turret ejector can aim the stinky stream in all directions as it uses muscles to swivel the nozzle. The blast of fluid is released in super-fast pulses up to 500 times per second to prevent the beetle itself from being scalded.

The noxious jet of boiling fluid, which is also extremely smelly, confuses and, in some cases, can even immobilise the would-be assassin giving the beetle plenty of time to make its escape.

Ejection nozzle
The catalysts cause a violent exothermic (heat-producing) reaction that releases a lot of heat energy. This vaporises most of the liquid in the chamber causing it to expand and explode out of an opening at the end of the abdomen.

Reaction chamber
Danger triggers a lightning-quick response from the beetle that opens a valve in the reservoir and quickly releases the acidic concoction into a second chamber where enzyme catalysts are added.

Taking aim
Muscles around the exit passage direct the jet of boiling steam in almost any direction with incredible precision, temporarily stunning the bug's foe.

Chemical stores
Two concentrated primary reagents (hydrogen peroxide and hydroquinone) are secreted from glands in the beetle's abdomen into a chemical reservoir.

"The combination of fast-flowing water and obstacles like rocks causes the flow to become turbulent"

White-water rapids

Discover which part of a river's course provides the setting for some of the world's most dangerously turbulent water

The Huka Falls is a series of waterfalls that drops over 11m (36ft) on the Waikato River in New Zealand

White water occurs in the upper course of the river when the gradient and obstacles disturb the flow of water, causing it to churn and create bubbles. These bubbles reflect back much of the light that hits them, making the water appear white. Whether a river flows smoothly often depends on its speed, and the steeper the riverbed, the faster the water will flow.

The combination of fast-flowing water and obstacles like rocks causes the flow to become turbulent, with unpredictable variation in the speed and direction of the water. This creates a variety of features in the river. Where water doubles back on itself, pockets filled with bubbles open up; these provide much less buoyancy and feel like 'holes'. Objects lodged in the river, like trees, can act as strainers, allowing water to pass through, but blocking the passage of larger debris. And in areas where the water moves rapidly, it wears away at the surface of rocks underneath, creating undercuts.

The challenges of navigating the variable features of white-water rapids – whether they be jutting rocks, whirlpools or pressure waves – attract thousands of adrenaline-junkie kayakers and rafters every year.

© Thinkstock

How do spiders sometimes make a quick getaway?

A Ballooning B Paragliding C Diving

Answer:
Spiders can get airborne by spinning a single strand of silk and waiting for a breeze. When the velocity of upward air flow causes drag that exceeds the pull of gravity an arachnid can take off on the breeze, a phenomenon known as ballooning.

DID YOU KNOW? *A farm in Australia was also overrun when subterranean wolf spiders sought refuge from flood water*

How insects survive floods

Discover what happened when flash flooding forced creepy-crawlies to take to higher ground

This photo taken by the UK's Department for International Development (DFID), following an unprecedented monsoon season in Pakistan, reveals the dramatic effect severe flooding can have on local environments.

In July 2010 the same amount of rain that would typically fall in a decade fell in a week in southern Pakistan, and the water didn't recede for months.

The extent of the flood spanned an area the size of the UK and forced the local wildlife – including birds, animals and insects – to seek refuge on higher ground. Four months later something remarkable began to happen: all the trees and other plantlife in the region started to develop ghostly white veils of silk. Millions of spiders, as well as other bugs, were spinning webs in the trees high over the water.

An interesting reported side effect of this unusual natural phenomenon was that, despite the fact the water was receding slowly and leaving massive pools of stagnant water, mosquito numbers remained relatively low. This was unusual because still water conditions are ideal for helping complete the mosquito life cycle. Authorities had therefore expected the mozzie population to soar; instead numbers were down. The mosquitoes were thought to be getting ensnared in these blankets of silk. This positively impacted on public health by reducing the incidences of malaria in the area as a result.

"Underground rivers like the Puerto Princesa are found in a type of limestone terrain called karst"

Subterranean rivers

Discover how, over many millennia, water can create spectacular cave systems and secret waterfalls all hidden deep beneath the ground

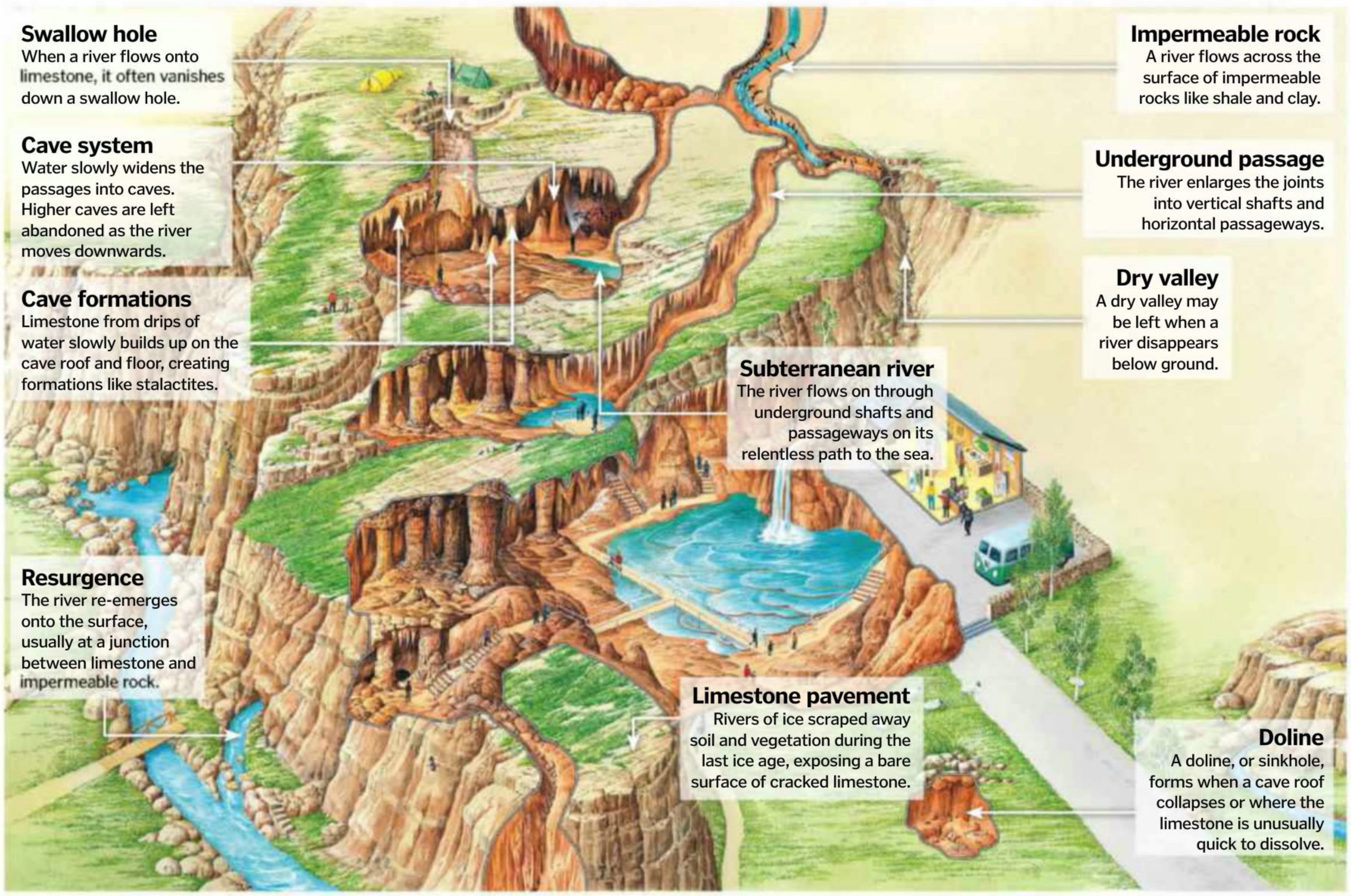
On the island of Palawan in the Philippines is a layer of limestone over 500 metres (1,640 feet) thick. The rock is honeycombed with a complex network of caves – some big enough to hold jumbo jets – that have formed due to running water from rain and streams. Deep inside the limestone is the Puerto Princesa Subterranean River, which flows 8.2 kilometres (five miles) through a warren of passages to the sea.

Underground rivers like the Puerto Princesa are found worldwide in a type of limestone terrain called karst. These dramatic landscapes are riddled with huge caves, pits and gorges. Famous examples include the South China Karst, which covers 500,000 square kilometres (193,000 square miles) of China's Yunnan, Guizhou and Guangxi provinces.

Karst forms when acid water seeps down tiny cracks, called joints, in the limestone. The acid slowly eats away the rock and enlarges the joints into vertical shafts and horizontal passages. Rivers flowing onto limestone often vanish from the surface down shafts called swallow holes and continue as underground waterways. Generally, dry valleys signal where the river once flowed on the surface.

Over millions of years, underground rivers can carve out huge cave networks – some that extend for hundreds of kilometres. Higher caves are left abandoned when gravity causes the river to drain into lower passages. The water seeps down through the limestone until it reaches impermeable rocks, then flows horizontally until it emerges near the base of the karst as a spring or waterfall.

During floods, or when the water table rises, the river can totally fill a cave and erode its roof. When the water retreats, the unsupported ceiling may crumble. The Reka Valley in Slovenia – a 100-metre (328-foot)-high gorge – formed when a cave collapsed centuries ago. This means the Reka River, which primarily runs underground through the Škocjan Caves, now sees daylight for part of its journey.



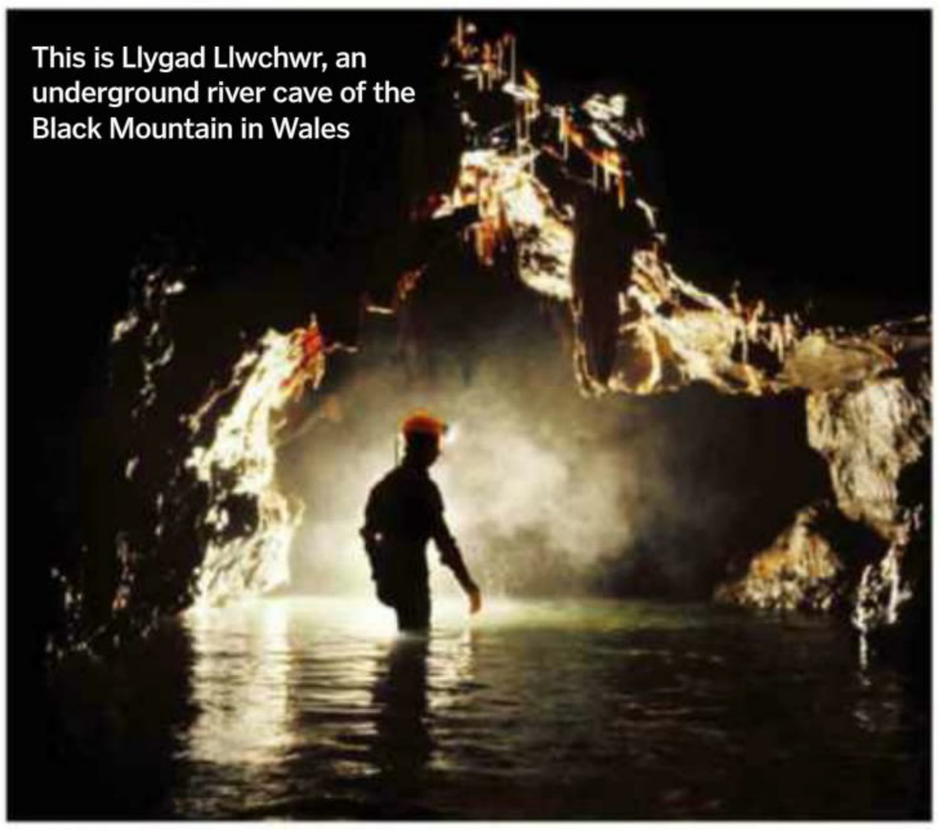
THE STATS
CLEARWATER CAVE, MALAYSIA

RIVER FLOW **150,000 tons/hr** LENGTH 189km AVERAGE DIAMETER **16m**

FIRST DISCOVERED 1978 VERTICAL RANGE **350m** VOLUME 37mn m^3

DID YOU KNOW? *A 20-million-year-old fossil of an aquatic mammal is embedded in the walls of the Puerto Princesa cave*

1,200m below the Jordanian Plateau, this slot canyon fed by a spring flows through a narrow sandstone gorge to the Dead Sea



This is Llygad Llwchwr, an underground river cave of the Black Mountain in Wales

How limestone dissolves

Limestone is made of the shells of tiny sea creatures that lived millions of years ago. Shells contain calcium, just like bones and teeth. Limestone is more than 80 per cent calcium carbonate and – like teeth – is decayed by acid.

Rain and stream water absorb carbonic acid from the atmosphere and humic acid from decaying vegetation in the soil. When water seeps down limestone joints, the acid dissolves the calcium carbonate. Calcium bicarbonate is formed and washed away – sometimes in huge quantities. An estimated 600 tons of calcium bicarbonate are removed daily by the waters of Silver Springs in Florida, USA, for instance.

Limestone landforms

1 Swallow hole
Rivers can disappear underground down openings called swallow holes. Swallow holes like Gaping Gill in Yorkshire, UK, form where limestone is heavily fractured and jointed. Gaping Gill is also the site of Britain's highest unbroken waterfall.

2 Caves
Earth's largest underground chamber is in a karst formation. Borneo's Sarawak Chamber is 100 metres (328 feet) high and 700 metres (2,297 feet) long. It's so wide it could fit in eight jumbo jets!

3 Limestone pavement
A famous example of a limestone pavement lies above Malham Cove, a cliff in the Yorkshire Dales. This bare rock surface formed during the last ice age when glaciers scraped away soil to expose the limestone. It consists of slabs called clints, separated by cracks known as grikes.

4 Dry valley
Cheddar Gorge in Somerset is Britain's biggest dry valley. It too formed during the last ice age when cracks in the limestone filled with ice. Water couldn't penetrate the rock so it flowed across the surface, gouging out a gorge.

5 Stalactites and stalagmites
Caves contain many stunning formations like stalactites and stalagmites. These spikes of rock form when water drips from the ceiling, leaving traces of limestone on the roof and floor over many centuries.

ON THE MAP

Underground river caves around the planet

1 Puerto Princesa River, Philippines
2 Phong Nha, Vietnam
3 Križna Jama Cave, Slovenia
4 Rio Secreto, Mexico
5 Santa Fe River, FL, USA
6 Sof Omar, Ethiopia

Secrets of the synchrotron

Find out how the UK's largest laboratory can accelerate electrons to nearly the speed of light

Electromagnetic (EM) radiation is incredibly useful. It enables us to transmit music wirelessly over large distances, cook food in our microwaves and see the world around us in vivid detail. However, now more than ever, electromagnetic radiation is also crucial in studying the physical, environmental and life sciences that are making real breakthroughs for people on a day-to-day basis. From the creation of new drugs and vaccines, through to the testing of revolutionary artificial organs and on to discoveries that allow diseases to be prevented, the harnessing of EM radiation on a large scale is truly expanding horizons in the scientific world.

In the UK, that revolution is happening at the Diamond Light Source national synchrotron facility in Oxfordshire. A high-tech particle accelerator that excels in generating vast quantities of EM radiation in the form of synchrotron light. How It Works decided to take a trip to this cutting-edge science site to see what work there is like on an average day and what ground-breaking experiments are currently being investigated...

Exploring the synchrotron

A good place to start would be to explain what a synchrotron actually is. Essentially it's a large, complex system of machines that generates electrons, accelerates those electrons to near light speed and then deposits them in a large storage ring. The high-energy electrons then fly around the ring circuit continuously until they are manipulated to generate very high intensity, X-ray light; we are talking about electrons with around three gigaelectronvolts (GeV), a GeV being a unit of energy equal to a billion electron volts. This is the light that scientists can utilise in their experiments.

Right now we're about to meet with Dr Guenther Rehm, head of the Diamond Synchrotron's Beamline Diagnostics Group. This is the team responsible for ensuring that when visiting scientists need X-ray light, they get it.

We step through from Rehm's office in Diamond House, a sleek, glass-walled complex in which the majority of the facility's 400 staff is based. Then once we're across the security-controlled bridge into the synchrotron facility proper, he begins to describe how the system works.

The synchrotron here consists of four main parts, the first of which is an electron gun. Sitting at the heart of the facility, this gun is responsible for generating electrons – by heating a high-voltage cathode in a vacuum – and then forcing them to bunch up together and compress into compact groups; the latter is achieved by passing the beam of electrons through a cavity where an alternating electric field is active.

From the bunching cavity, a beam of compressed groups of electrons passes into a linear accelerator. This part of the synchrotron uses a series of electric fields to force the compressed groups of electrons in the stream to accelerate to close to the speed of light and up to a charge level of approximately 100 MeV. From here the sped-up bunches of electrons are injected into the booster synchrotron.

The booster synchrotron sits just off the linear accelerator. It is a 158m (518ft), 'O'-shaped stainless-steel tube vacuum surrounded by magnets that sits within the synchrotron's storage ring and other facilities. This smaller synchrotron receives the electrons and then, with the help of 36 dipole magnets, bends them around the vacuum circuit while they are accelerated further up to the necessary extraction energy of three GeV. Travelling at almost the speed of light and carrying an insane energy level, the electron bunches are lastly injected into the synchrotron's storage ring.

The storage ring is similar in both build and purpose to the booster ring, but on a far larger scale. The storage ring consists of a vacuum in which the charged electrons travel, a series of magnets including dipole-bending magnets to manoeuvre the beam around the circuit, quadrupole and sextupole magnets to ensure accurate beam focus

One of the synchrotron's sextupole magnets. These are responsible for achromatic correction and maintenance of a stable electron orbit within the facility's storage ring

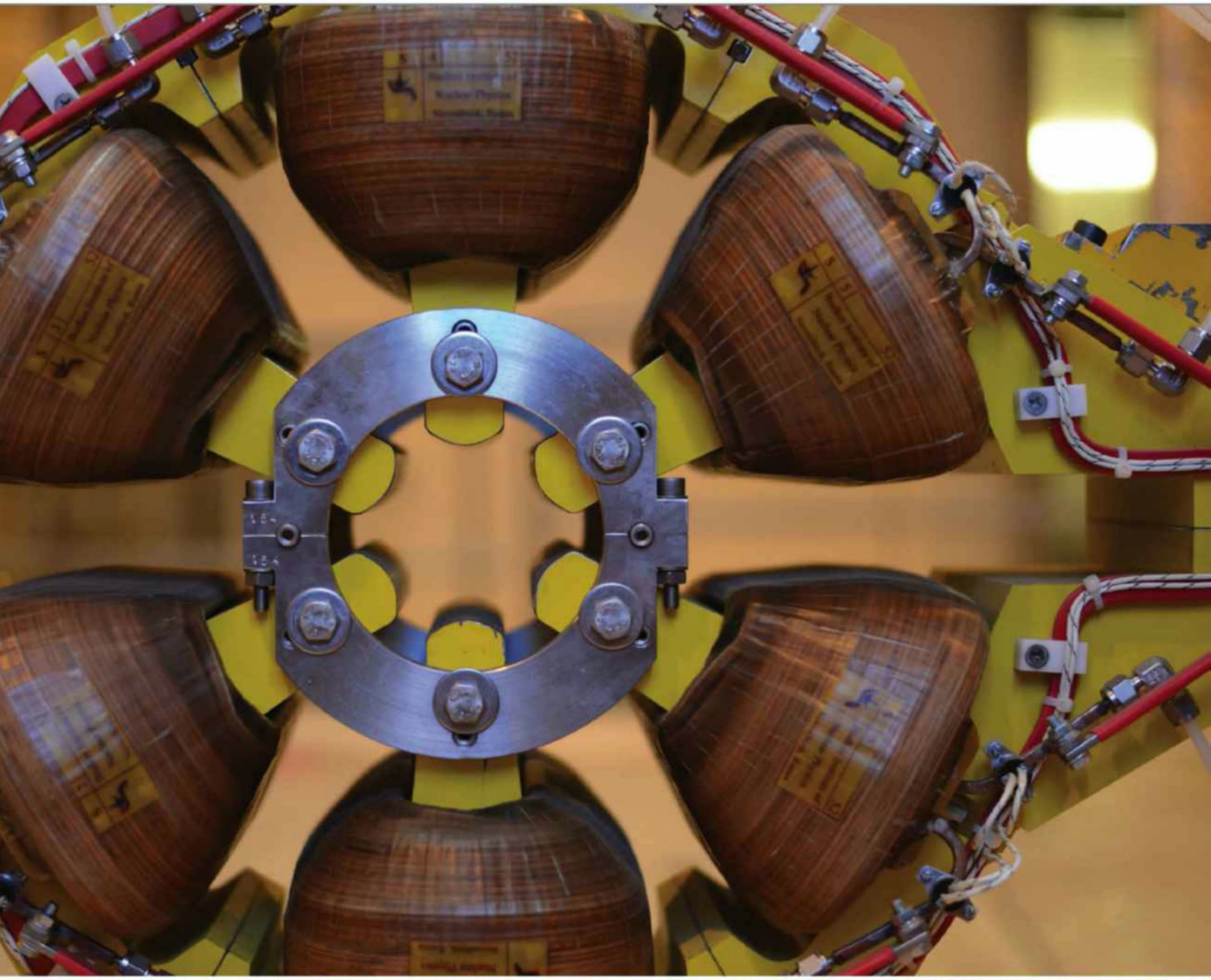
AMAZING VIDEO!

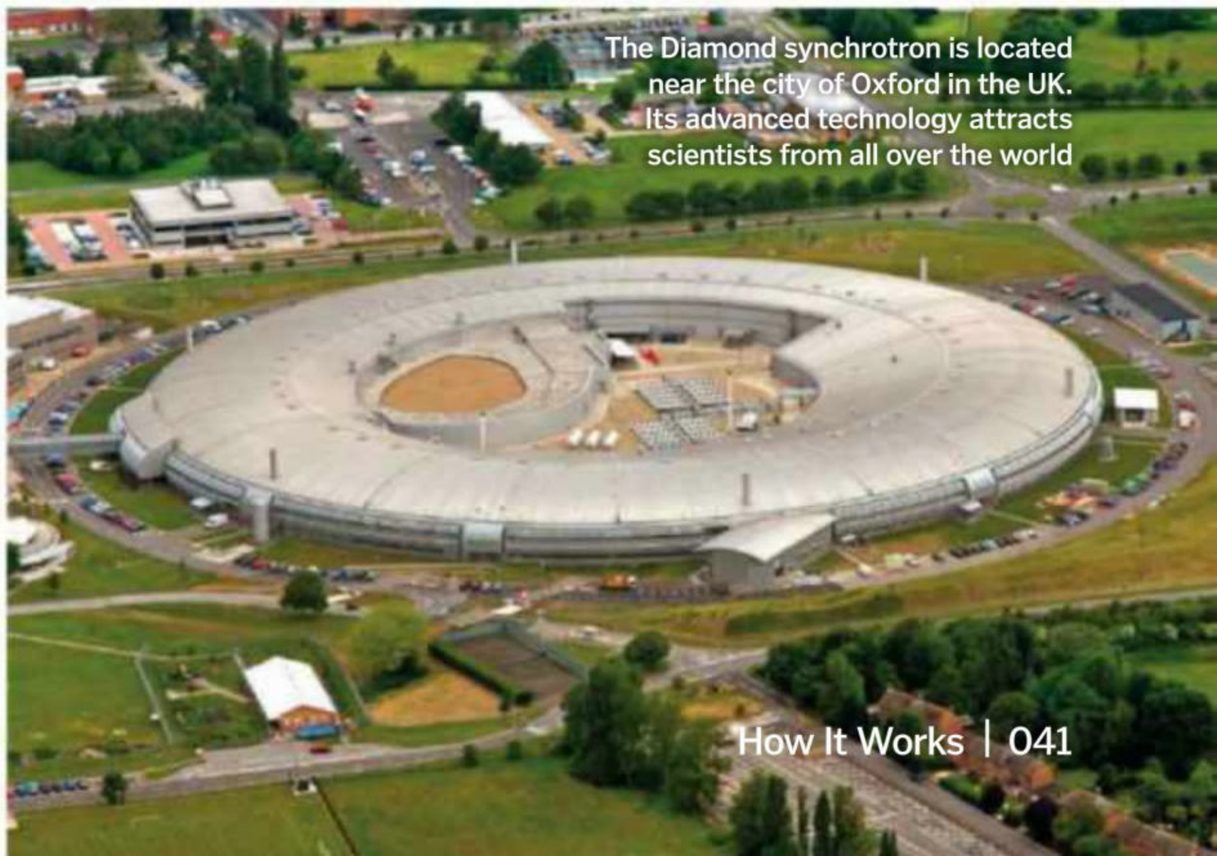
SCAN THE QR CODE FOR A QUICK LINK

Engineers install a new ID into the synchrotron

www.howitworksdaily.com

DID YOU KNOW? *By 2018, the Diamond synchrotron will boast 32 beamlines*





The Diamond synchrotron is located near the city of Oxford in the UK. Its advanced technology attracts scientists from all over the world

"The IDs are the real stars of the synchrotron, forcing electrons to oscillate around their straight course"

and position, as well as special magnets called insertion devices (IDs) to manipulate electrons for synchrotron light production.

The IDs are the real stars of the synchrotron, capable of forcing passing electrons to oscillate around their straight course. As a result of their resistance, super-powerful X-rays are produced. As such, prior to any beamline – offshoots from the ring where experiments take place – you'll find an ID. The electrons enter the device, oscillate, create X-rays and then, while the electrons are flung farther down the storage ring by dipole magnets, photons continue straight, down the beamline for use in experiments.

Staying in control

Next we arrive at beamline central control. A large spacious room overlooking approximately a third of the expanding facility, the area is filled with a main bank of monitors, two members of the diagnostics team manning computer systems. Rehm explains that the day-to-day operation of the synchrotron is heavily automated, hence the minimal staffing. However, due to the incredible complexity of the systems involved in creating and maintaining high-energy electron beams, the status of the complex has to be constantly monitored. Indeed, we had expected that controlling an electron beam of such magnitude would be no easy feat.

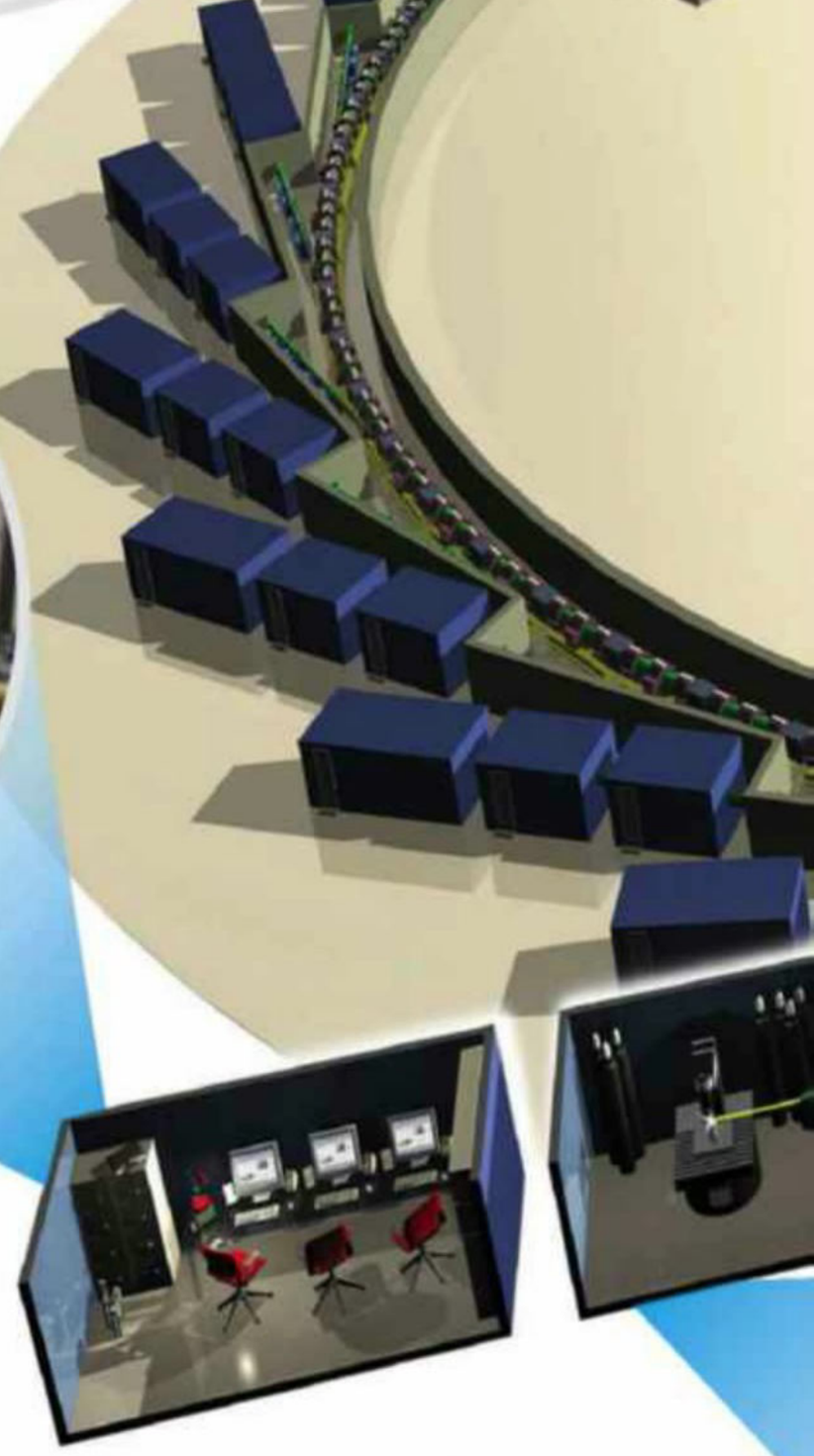
At all times the beam in the storage ring at the synchrotron is analysed within the control room for charge level, position, time structure and electron losses. This is done through a piece of software referred to as EPICS: Experimental Physics and Industrial Control System. This allows the invisible beam's properties to be visualised via a variety of sensors, monitors and cameras within the ring.

In a demonstration of how this works, Rehm shows how over a ten-minute period the bunched electrons in the storage ring suffer inevitable loss. This is due to collisions and residual gas molecules, as well as energy loss through the generation of synchrotron light by the insertion devices and bending by the dipole magnets. To maintain optimal beam stability and synchrotron light quality, it is automatically topped up periodically. Watching a live graph in EPICS, we see how the overall charge level drops within the ring and then, precisely after ten minutes, returns back to its start level.

Rehm explains that not only is this topping up automatic, but the system can actually target the parts of the beam in which the electrons have

Diagnostics centre
The synchrotron's operation is controlled and monitored from a central control room. Despite many systems being automated, the room is permanently staffed in case of a serious error.

Control cabin
This is the final hutch of each beamline and is where the scientific teams monitor and control their experiments and equipment.



IDs up close

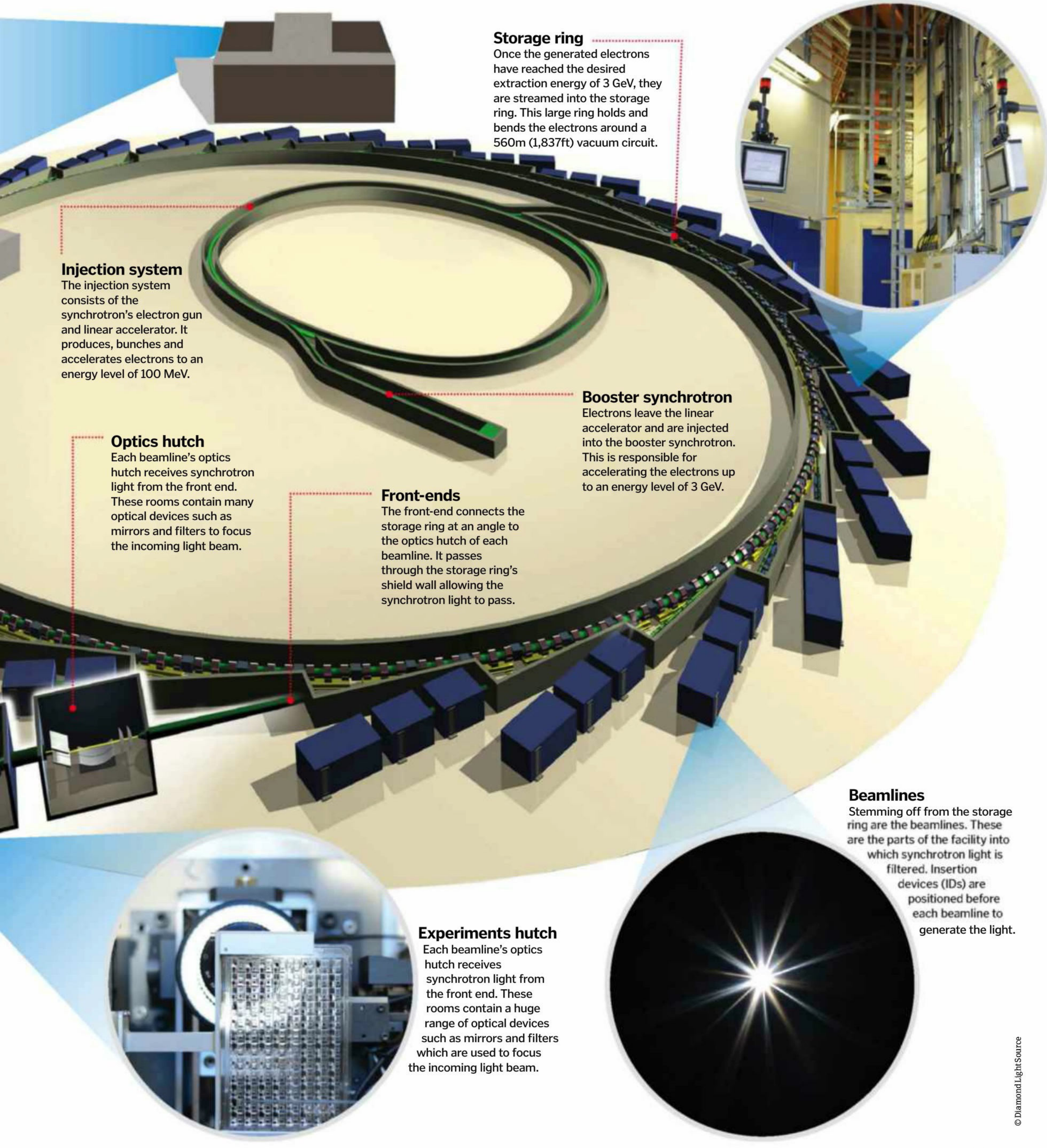
Insertion devices (IDs) are arrays of incredibly strong magnets lined up in two rows – top and bottom – next to each other in tight lines that have very strong magnetic fields. The magnets are arranged to generate a specific pattern of vertical alternating magnetic field that, when electrons pass through it, causes them to oscillate (vibrate back and forth). This oscillating motion generates synchrotron radiation/light in the form of photons, which can then be siphoned off for various different experiments in synchrotron facilities.

RECORD BREAKERS
ELECTRONS

300,556 KILOMETRES ELECTRONS TRAVEL

Electrons in the synchrotron's storage ring complete a circuit in just 2-millionths of a second, that's the equivalent of travelling around the Earth's equator 7.5 times, a distance of 300,556km.

DID YOU KNOW? *The storage ring is actually not a circle, but a 24-sided polygon*



Storage ring
Once the generated electrons have reached the desired extraction energy of 3 GeV, they are streamed into the storage ring. This large ring holds and bends the electrons around a 560m (1,837ft) vacuum circuit.

Injection system
The injection system consists of the synchrotron's electron gun and linear accelerator. It produces, bunches and accelerates electrons to an energy level of 100 MeV.

Booster synchrotron
Electrons leave the linear accelerator and are injected into the booster synchrotron. This is responsible for accelerating the electrons up to an energy level of 3 GeV.

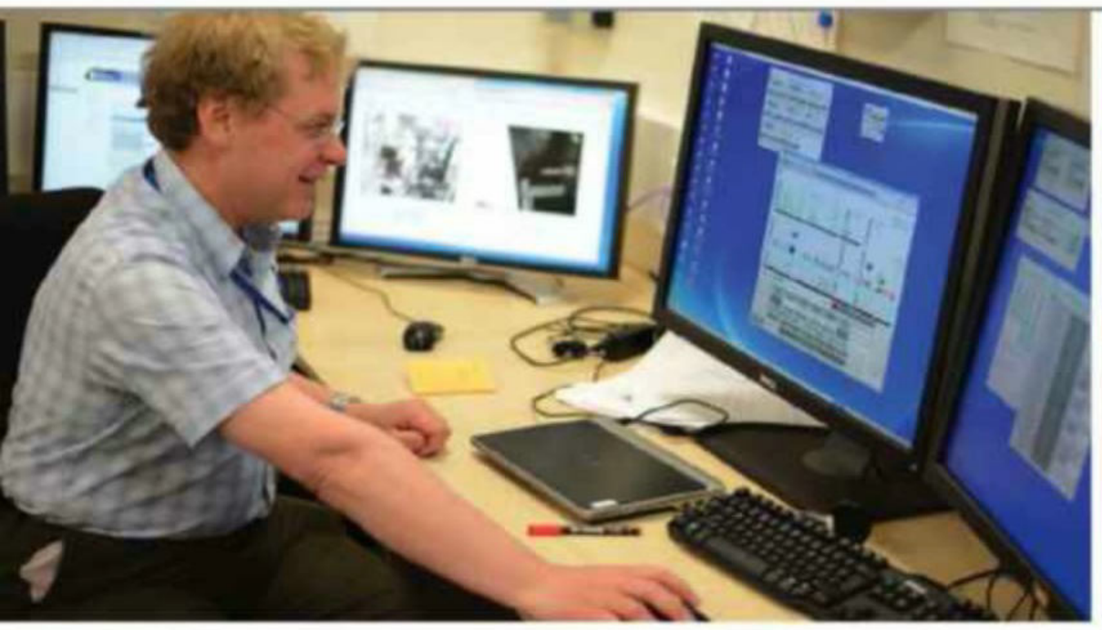
Optics hutch
Each beamline's optics hutch receives synchrotron light from the front end. These rooms contain many optical devices such as mirrors and filters to focus the incoming light beam.

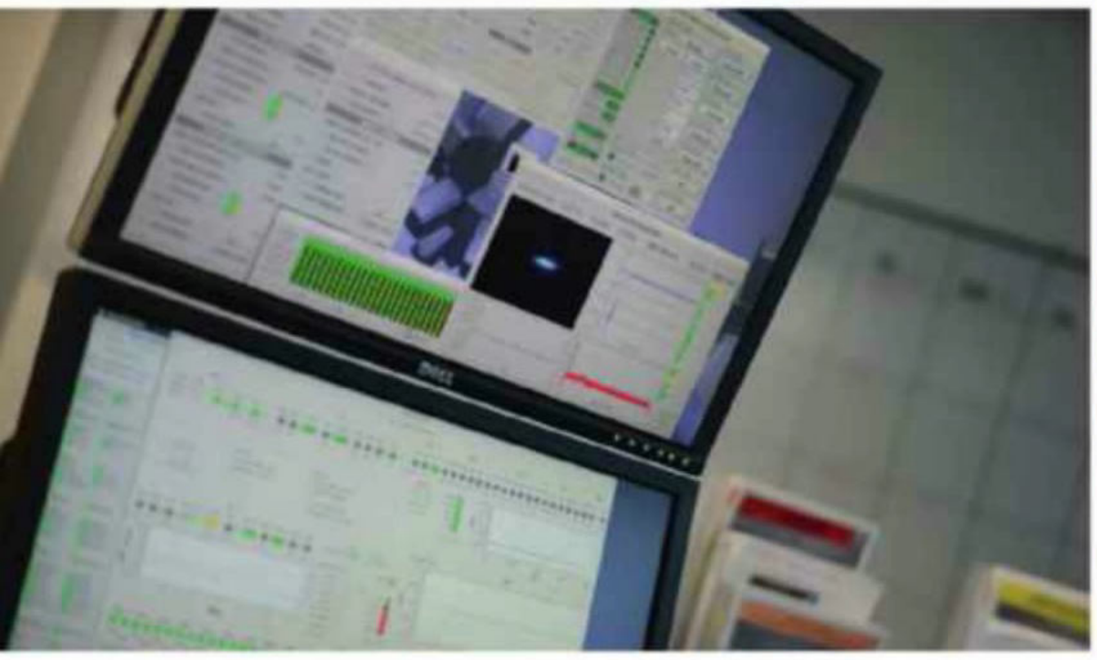
Front-ends
The front-end connects the storage ring at an angle to the optics hutch of each beamline. It passes through the storage ring's shield wall allowing the synchrotron light to pass.

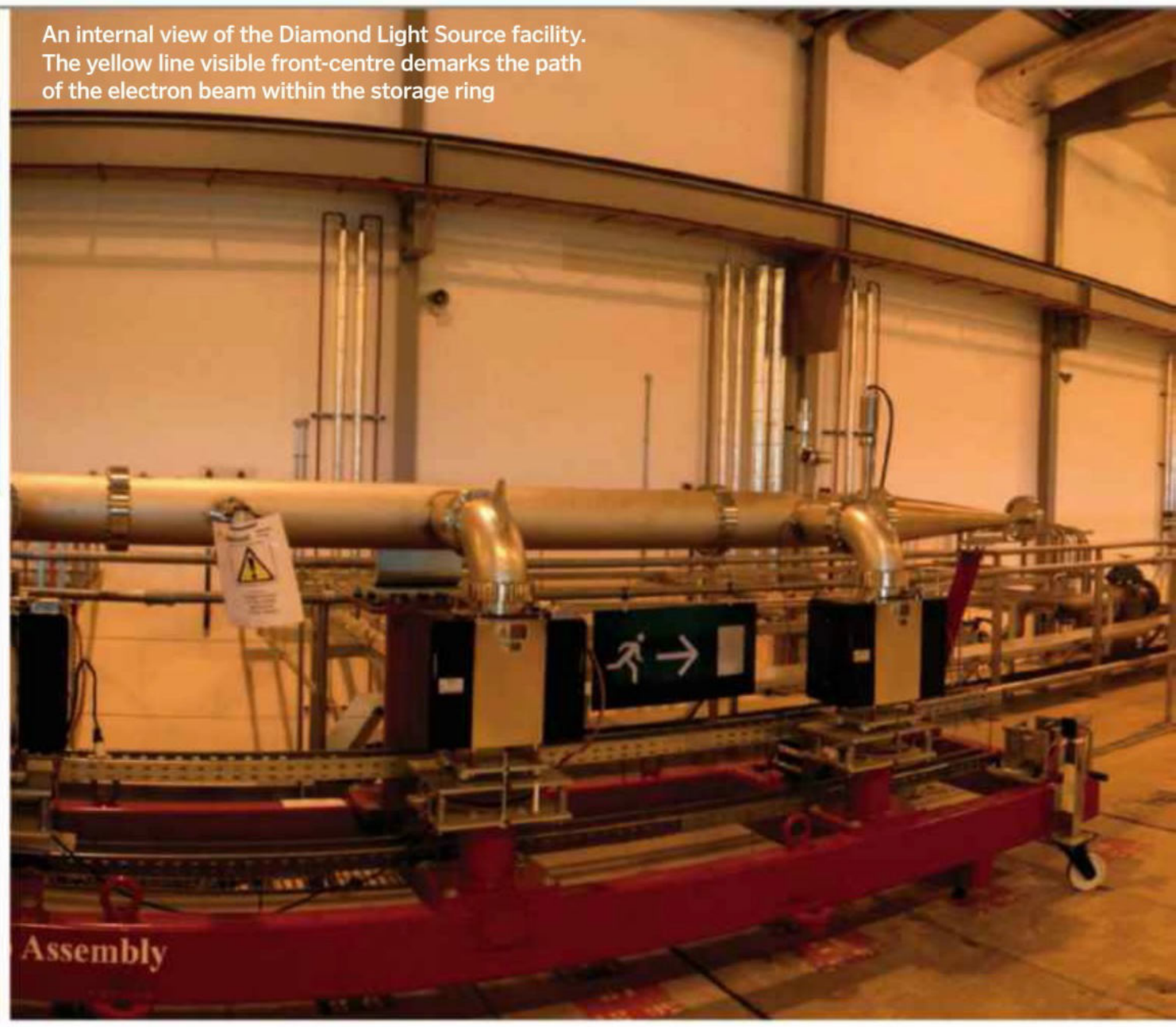
Beamlines
Stemming off from the storage ring are the beamlines. These are the parts of the facility into which synchrotron light is filtered. Insertion devices (IDs) are positioned before each beamline to generate the light.

Experiments hutch
Each beamline's optics hutch receives synchrotron light from the front end. These rooms contain a huge range of optical devices such as mirrors and filters which are used to focus the incoming light beam.

"The ability to image reaction processes at atomic levels and microsecond time scales is mind-blowing"







An internal view of the Diamond Light Source facility. The yellow line visible front-centre demarks the path of the electron beam within the storage ring

been lost from; this makes for an even, stable distribution of energy around the ring for light generation at all times. This system is truly amazing, capable of injecting additional electrons into the depleted electron bunches smoothly as they fly around the storage ring at almost light speed.

Looking down the beamline

Moving to the heart of the facility, we enter the cavernous main room of the synchrotron. Standing on an elevated gantry bridge, stretching out to both sides, the curved expanses reveal many of the synchrotron's individual beamlines, branching off from a concrete ring. Rehm explains that this is the facility's storage ring, albeit encased within metre-thick, radiation-blocking concrete shielding. On top of the concrete ring is a yellow line – this identifies the actual path of the electron beam inside. According to our guide, a person could lie on top of the concrete for an entire year and only receive a radiation increase of approximately 50 per cent over that from standard background radiation. Simply put, very little radiation escapes the ring.

As we progress to get a better look at the storage ring and beamlines, Rehm begins to tell us about a major challenge of his occupation: consistency of run time.

Despite the synchrotron having a day's downtime every week for maintenance, trying to keep all the various systems and subsystems working together continuously without failure is challenging. Scientists are visiting the facility 24/7 and spend months applying and waiting for their chance to use a beamline, so any unscheduled downtime is keenly felt.

It is some of those scientists that How It Works is about to meet, but first Rehm has one more stop. Sandwiched between two beamlines is a small, black room. On entering, we find a large table stuffed with machines, pipes, optics and cabling. Behind this, a small hole is cut in the wall. This is the Optics Diagnostics Cabin and it allows the support scientists to explore the temporal structure of the stored electron beam, revealing its fill pattern (how much charge is in each of the electron bunches). Rehm holds his hand in front on the incoming beam of light to reveal its apparent weakness, like a faint splodge. We then look down the incoming beam and are immediately dazzled by a piercing bright light. This is but a minuscule replica of the high-energy synchrotron light in the beamlines.

Handling the light

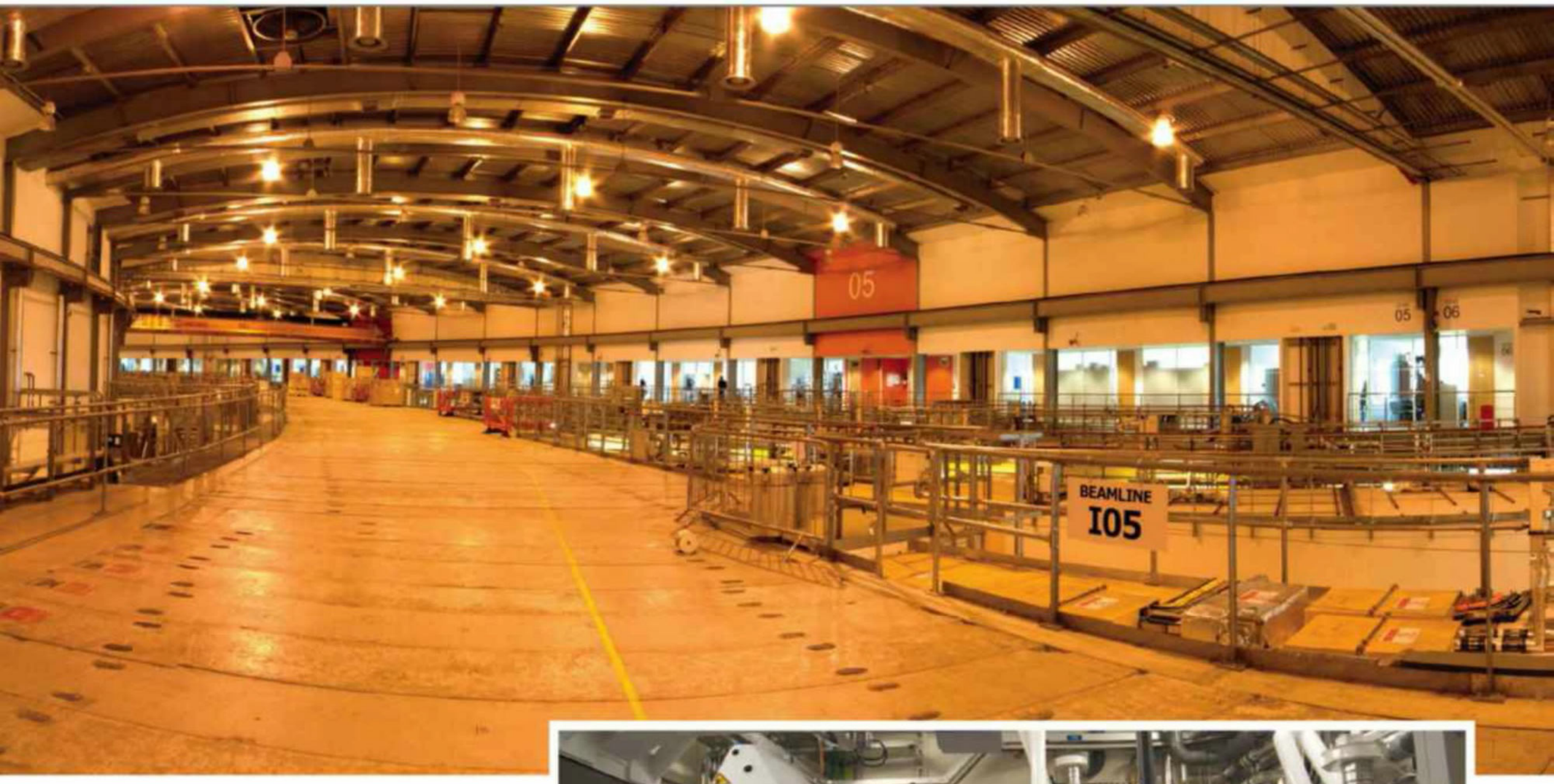
Knowing how the synchrotron works is one thing, but what does it actually mean for the world at large? Enter Professor Nick Terrill, the principal beamline scientist for the small angle scattering and diffraction beamline (I22). Among many other examples, Terrill described how a team recently had used I22 to test new polymer-material artificial heart valves. The team built a tiny device to stretch the valve to reproduce the effects of a heart beat and then used the synchrotron's high-energy X-ray light source to image the internal structure of the polymer valve in continuous resolution over a long period. It is hoped these sort of polymer valves could soon replace the problematic mechanical and animal implant valves currently used.

After a short walk around the synchrotron's outer walkway to beamline I24, we come across the microfocus macromolecular crystallography station. I24 is staffed by Diamond's senior support scientist, Dr Danny Axford, who explains how the team is working on membrane proteins, exploring their structures –something of vital importance in the creation of new drugs among other applications. This project is a collaboration between Imperial College London and Diamond itself. It is making use of both the on-site Membrane Protein Lab, which negates the need to transport samples and potentially damage them, as well as a new technique in

THE STATS SYNCHROTRON

AREA OF FACILITY 43,300m²
STORAGE RING SIZE **562m**
COST TO BUILD £260mn
STORAGE RING BENDING MAGNETS **48**
CURRENT NUMBER OF BEAMLINES 22
ELECTRON BEAM CHARGE **3 GeV**

DID YOU KNOW? *Over 400 people work at the Diamond synchrotron facility*

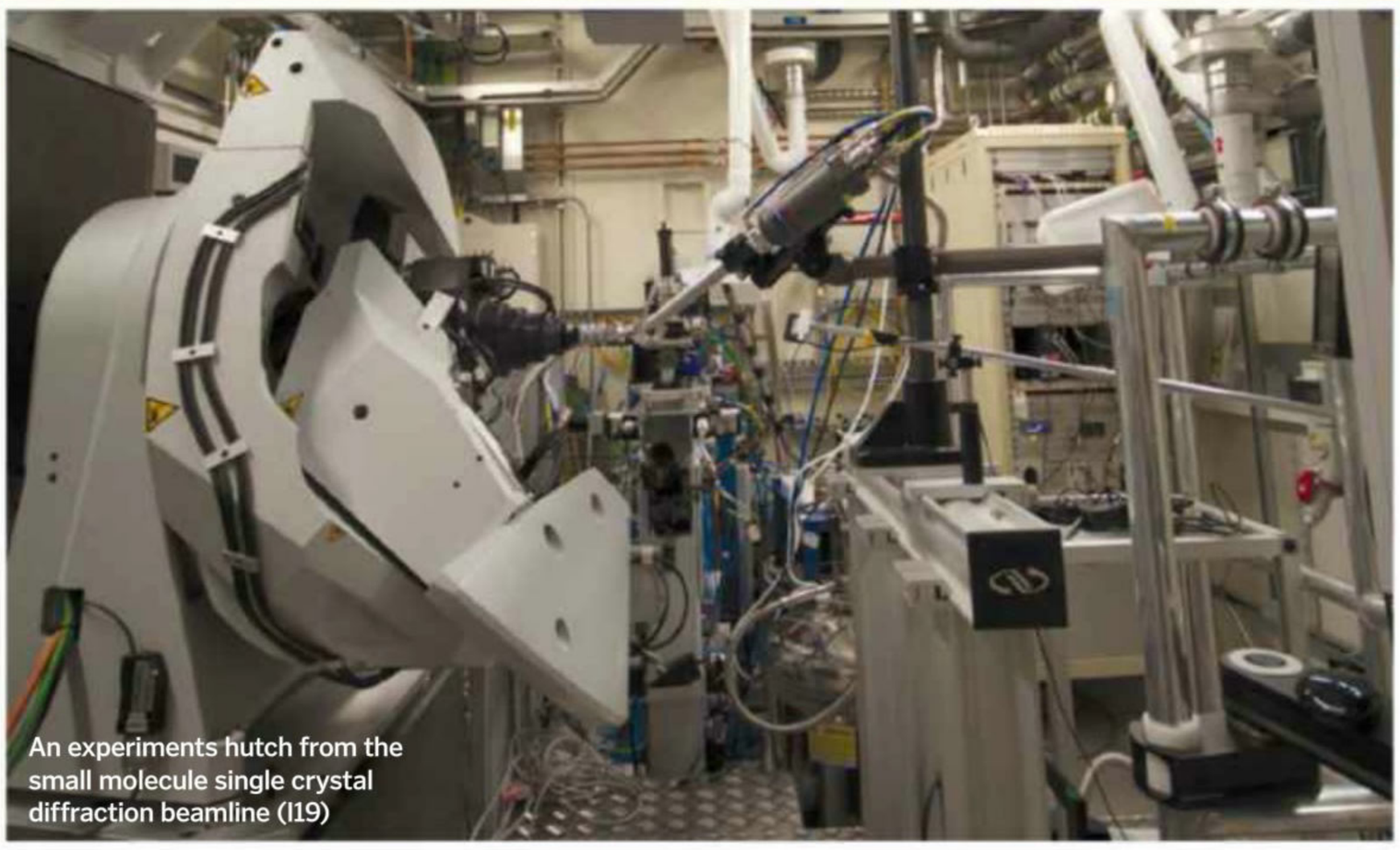


which a wide variety of crystal samples can be imaged in a short space of time.

After allowing the visiting scientists to finish analysing their current batch of samples, Axford opens up I24's experiment's hutch – the room containing the liquid-nitrogen storage tanks, imaging sensor, robotic arm, synchrotron light-focus optic and sample array all needed to perform experiments. The sensor in this room is state of the art and, alongside the sample-holding array, allows rows of crystals to be imaged at room temperature. This is incredibly useful as heat from the imaging process damages crystals, so capturing their structure quickly is crucial – hence why many samples are cryogenically cooled.

Our next port of call is the small molecule single crystal diffraction beamline (I19), where we see how a variety of crystallised samples are being analysed through diffraction techniques with samples ranging in areas from cancer to hydrogen storage. Next door, in I20, we get a detailed tour of the impressive versatile X-ray absorption spectroscopy beamline by principal beamline scientist Dr Sofia Diaz-Moreno.

This beamline, which is much larger than any of the others, has two experiment hutches that share the line to enable different types of spectroscopy analysis. What really excites us is hearing about how important chemical components in catalysts – even in very low concentrations – can have their structure illuminated and imaged continuously. This ability to image reaction processes at an atomic level and at microsecond time scales is truly mind-blowing, and is allowing scientists to understand things like catalysts, metalloproteins (metal ion-containing proteins) and toxic materials like never before.


An experiments hutch from the small molecule single crystal diffraction beamline (I19)

Racing the electron beam

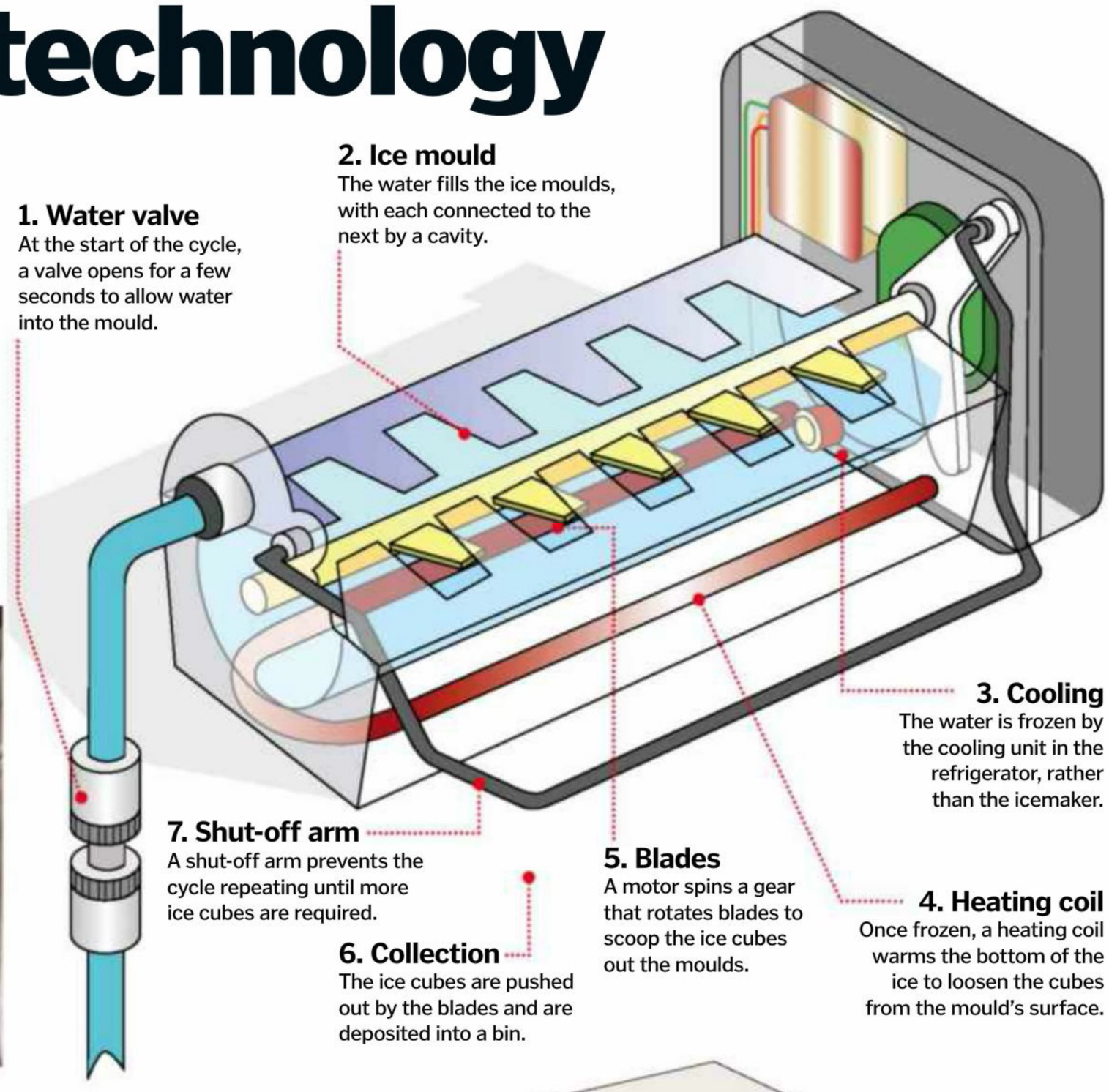
After witnessing first hand just how this impressive facility is enabling scientists to make radical breakthroughs in many fields of science, we have time for one final stop: a stroll on the roof of the storage ring. Ascending back up to the first floor from beamline level and crossing the metal gantry towards the centre of the facility, we break off and step directly on top of the concrete roof of the storage ring, before following the yellow beamline marker around the facility. It takes us close to ten minutes to make a full circuit around the ring; by way of comparison it takes the hyper-charged electrons beneath our feet just 2-millionths of a second.

"Some sensors detect body heat, while others send out waves that reflect off any moving object"

Icemaker technology

How do these machines produce ice cubes in bulk to keep our drinks cool?

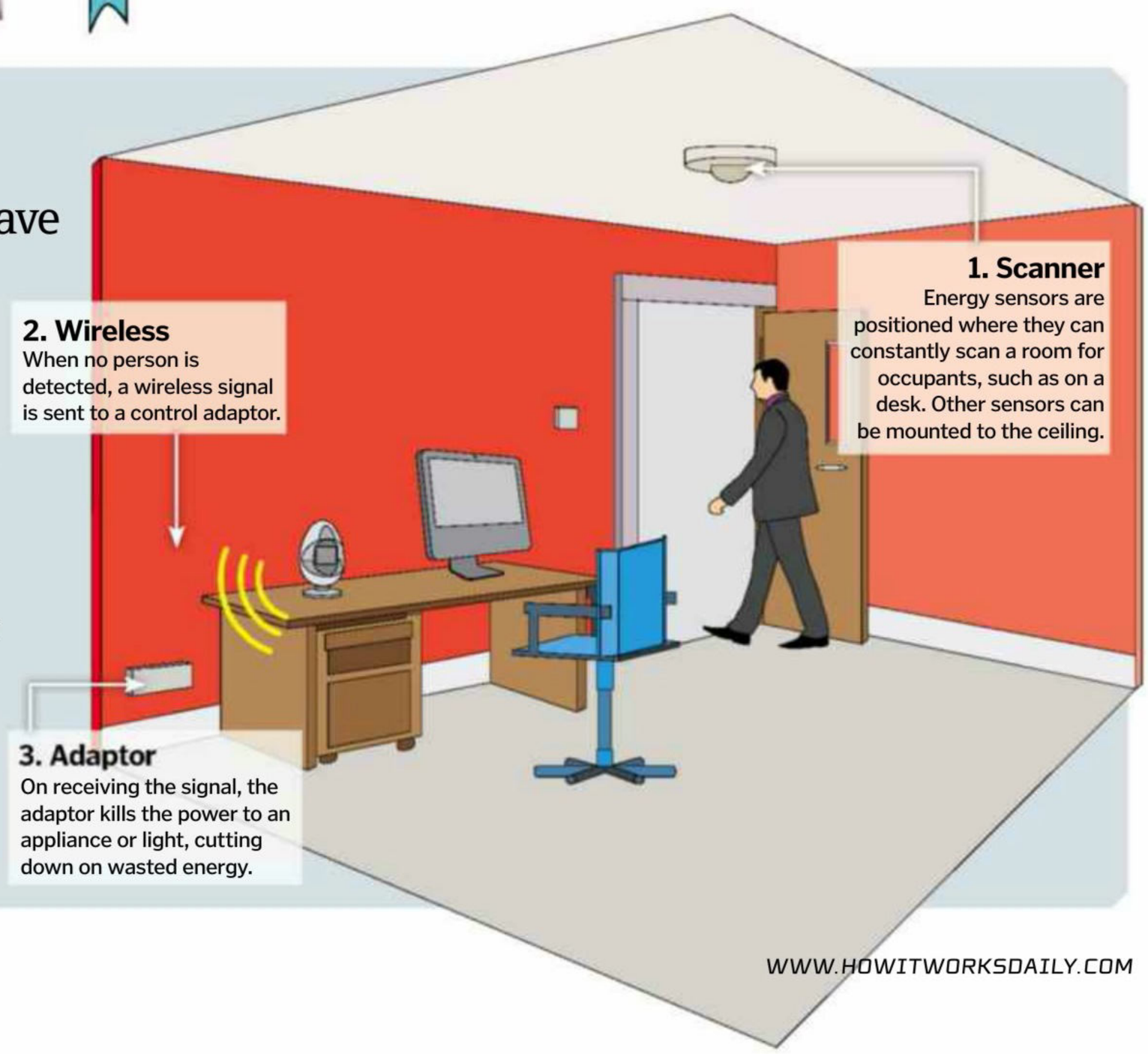
Icemakers are essentially a conveyor belt of ice cubes made for instant use. They come in a variety of shapes and sizes for different purposes, but almost all use the method of freezing water in a mould and then heating it slightly so the ice cubes slide out with ease. Here we look at how a conventional icemaker built into a domestic fridge-freezer works, like the one pictured below.



Eco sensors

Meet the gadgets helping to save the planet and our money

Smart energy-saving devices can detect when a room is empty using motion sensors and then turn off appliances through a control switch if no one is present. Some sensors detect body heat, while others send out waves (ultrasonic, microwave or radio) that reflect off any moving object. The former are generally preferred for energy-saving devices, as they can distinguish whether someone is standing or sitting still. When no person is detected, a signal is sent to a control box that is attached to an appliance – normally a plug socket or light switch – to turn it off. For convenience, most devices also have a time delay, so leaving the room briefly will not instantly turn off all your appliances.



KEY DATES
CAPTURED SPIES

1776 Nathan Hale was America's first spy; he was caught by the British during the American Revolution and hanged.

1780 John André spied for the British during the American Revolution but was also caught.

1917 Exotic dancer Mata Hari used social connections to gather intelligence for Germany in WWI.

1953 US communists Julius and Ethel Rosenberg (left) passed nuclear secrets to the USSR; both were executed in 1953.

1994 Aldrich Ames was a double-agent in the CIA for the Soviets. He is currently incarcerated.

DID YOU KNOW? *Moscow's US Embassy was so riddled with KGB bugs that it had to be torn down and rebuilt*

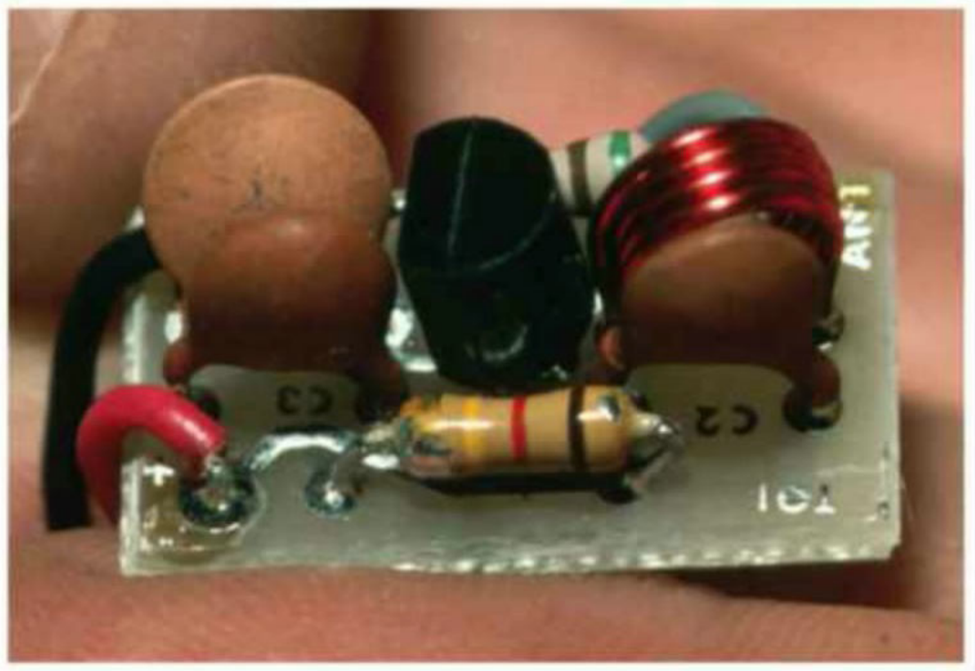
Face-detection technology

How does your digital camera recognise when it's pointing at a familar face?

Face-detection software is primed with a set of mathematical rules to describe the landmarks that identify a human face: typically two eyes, eyebrows, nose and lips. The image is first 'downsampled' by the software – to reduce the amount of information – and then it is analysed.

By measuring the differences between the shadows created by facial features, a camera can identify whether or not they match the expected layout of a face. Using the differences in contrast and shadow created by the whiteness of eyes and teeth, a camera is able to tell when a subject is blinking or smiling and can alter its settings accordingly, if so programmed.

Newer cameras are beginning to incorporate face recognition too. By taking a series of pictures of a person from several angles, the clever software is able to store information about the spacing of their unique facial features. This can then be used to give them autofocus priority when taking pictures in crowds, as well as to automatically tag the photographs.



Phone bugs explained

Learn how modern listening devices eavesdrop on our conversations

Traditionally bugs have two main components: a microphone to capture the audio and a radio transmitter to relay the conversation to the listener. The microphone is activated when sound reaches a threshold level, or when a radio signal of the correct frequency is sent to the device.

Newer bugging techniques take advantage of modern mobile phone and laser technology. GSM (Global System for Mobile Communications) audio bugs contain a SIM card. When called, the bug will automatically – and silently – answer, and pass on audio to the listener's phone. Laser listening devices, on the other hand, do not require a microphone at all, but detect the changes in vibration of objects as sound waves hit them. A laser aimed at a reflective surface, like a window, can detect minute changes in the vibration caused by shifts in air pressure as people talk. Laser bugs require the listener to be in line of sight of the target, but unlike microphone-based devices, no one needs to break into a property to plant the bug.

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See bomb-disposal suits being put to the test!

www.howitworksdaily.com

DID YOU KNOW? *The Advanced Bomb Suit (ABS) was used in the movie The Hurt Locker*

Bomb-disposal suits

How does this armour protect the technicians who disarm explosives?

Bomb-disposal suits are a form of specialised heavy body armour used by weapons specialists when diffusing explosive devices. They are used primarily by the military, but also see action in police forces. Their main role, not surprisingly, is to protect the wearer should the bomb unexpectedly detonate.

The suits are designed to mitigate the effects of intense heat, pressure and fragmentation – the debris from a bomb that flies off at high speed. This protection is achieved by combining several high-strength but low-weight materials such as Kevlar, Nomex, foams and a range of plastic composites, each layered and mixed to provide an all-round barrier to the effects of a blast.

As well as shielding the wearer, these advanced bomb suits are also responsible for keeping them connected to their team and as comfortable as possible. These factors are critical when out in the field, as often conditions can be extreme (such as in hot climates) and bomb disarmament is a very stressful operation. Built-in communication and ventilation systems ensure the technician stays informed and cool under pressure, respectively.

Over the past decade or so bomb-disposal suits have been in increasingly high demand, primarily due to the conflicts in Iraq and Afghanistan. This said, remotely controlled robots are now being used more and more to help avoid human casualties.

The history of disarming bombs

The earliest references to bomb disposal stem from World War II in England. Nazi Germany had undertaken a large bombing campaign against Britain, and a number of the devices that were dropped landed but failed to detonate. This caused a spiked increase in civilian deaths, with unexploded bombs accidentally being triggered during people's day-to-day lives.

This led the British government to begin training volunteer members of the public in bomb-disposal techniques, with groups tasked with clearing sites laden with buried and undetonated weapons. Unlike bomb-disposal units today, these civilians wore no protective clothing and had only very basic tools, having to make do with spades, axes and wire cutters.

Anatomy of the ABS

From head to toe, the materials and tools of the Advanced Bomb Suit explained

Helmet
The ABS's helmet is made from lightweight but high-strength fibre and weighs only 3.6kg (7.9lb). The visor is constructed from laminated acrylic and polycarbonate.

Raised collar
As an explosion can cause differential acceleration between the head and torso, each ABS is equipped with an articulated spine protector and supportive neck collar.

Comms system
The helmet is also equipped with a MIL-SPEC communications system, consisting of a microphone and set of speakers. It is powered by an internal battery pack that can last for about five hours.

Cooling system
Due to the multiple thick layers, a Nomex body suit with a woven capillary tube network is worn next to the skin. This is connected to a 2l (0.5ga) water reservoir that pumps ice-cold water around the ABS.

Ballistic panels
Composite ballistic panels are fitted to the outside of the suit in order to prevent bomb fragments entering at high speeds.

Lung overpressure deflector
Special rigid ballistic panels are placed over the chest. These offset panels are designed to absorb the high pressure generated on detonation, countering lung compression.

Materials
The suit is made from a mix of flame-retardant Nomex and Kevlar layers. These specialise in protecting the wearer from the intense heat generated in a blast.

© Alamy

"The drum is first given a uniform static charge and then a laser beam flashes across the surface"

Inside laser printers

How is it possible to print text and pictures using a beam of light?

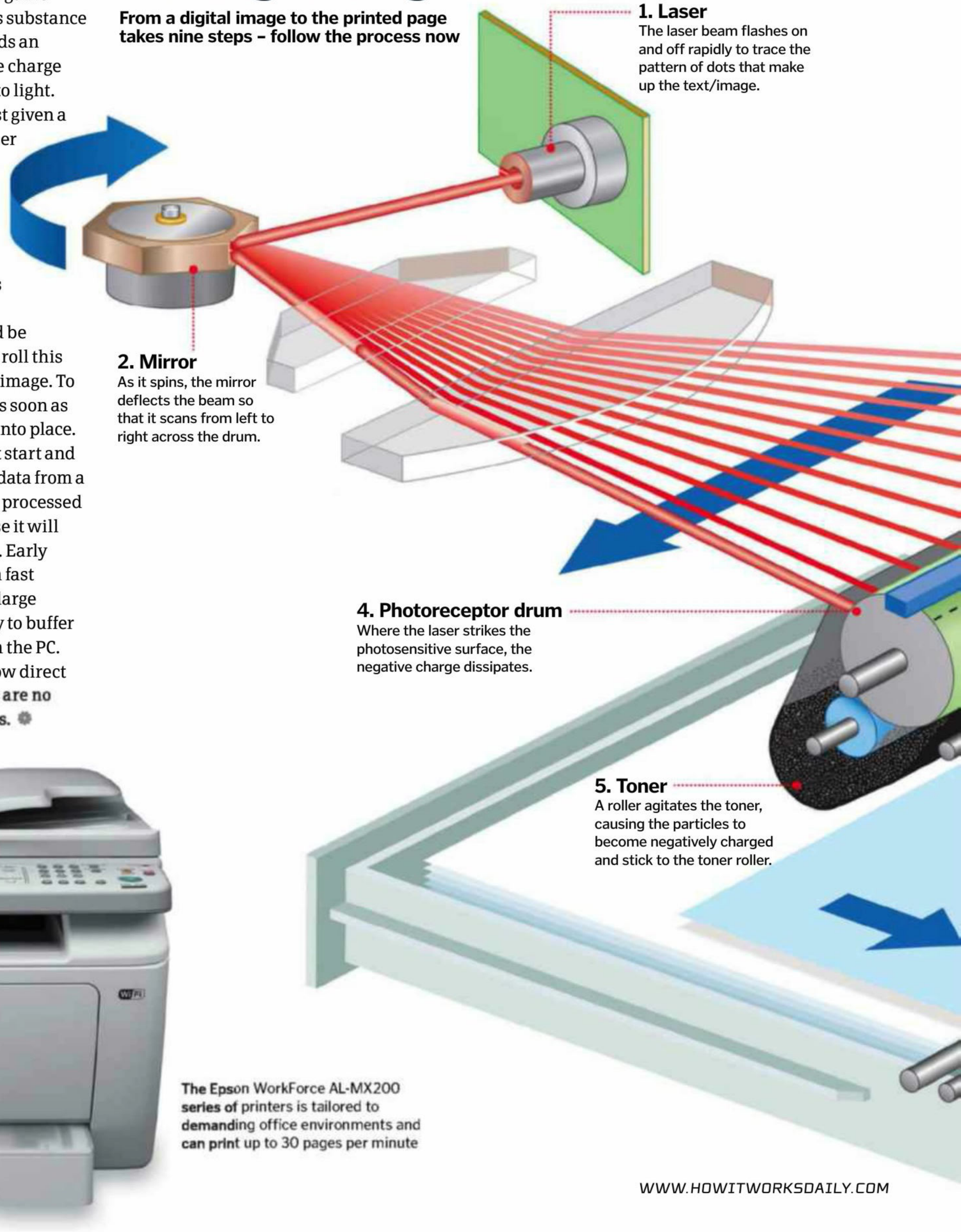
At the heart of every laser printer is a drum coated with an organic photoconductor (OPC). This substance has the unusual property that it holds an electrical charge in the dark, but the charge will dissipate if the OPC is exposed to light.

To print an image, the drum is first given a uniform static charge and then a laser beam flashes across the surface, erasing some of the charged areas, like drawing on a steamed-up window with your finger. If you roll this drum through a trough of specially charged pigment particles – called toner – they will stick to the uncharged sections of the drum and be repelled from the rest. You can then roll this onto a sheet of paper to transfer the image. To stop the toner falling off the paper as soon as the charge fades, it must be melted into place.

Unlike an inkjet printer, you can't start and stop the printer drum as it receives data from a computer. The entire page has to be processed in a continuous operation, otherwise it will leave smudges or lines on the paper. Early printer cables couldn't transfer data fast enough so laser printers had to use large amounts of expensive RAM memory to buffer the page until it had all arrived from the PC. Nowadays fast USB connections allow direct printing, and desktop laser printers are no more costly than their inkjet cousins.

Painting with light

From a digital image to the printed page takes nine steps – follow the process now



1. Laser
The laser beam flashes on and off rapidly to trace the pattern of dots that make up the text/image.

2. Mirror
As it spins, the mirror deflects the beam so that it scans from left to right across the drum.

4. Photoreceptor drum
Where the laser strikes the photosensitive surface, the negative charge dissipates.

5. Toner
A roller agitates the toner, causing the particles to become negatively charged and stick to the toner roller.

The Epson WorkForce AL-MX200 series of printers is tailored to demanding office environments and can print up to 30 pages per minute

KEY DATES
LASER PRINTING

1938 Chester Carlson develops a way of copying a printed page using electrically charged dry toner.

1960 The only company interested in Carlson's invention is the Haloid Photographic Company, which later becomes Xerox.

1969 Gary Starkweather (right), a researcher at Xerox, modifies the photocopier principle to allow it to print.

1984 The HP LaserJet is the first desktop laser printer. It weighs in at over 32 kilograms (70 pounds).

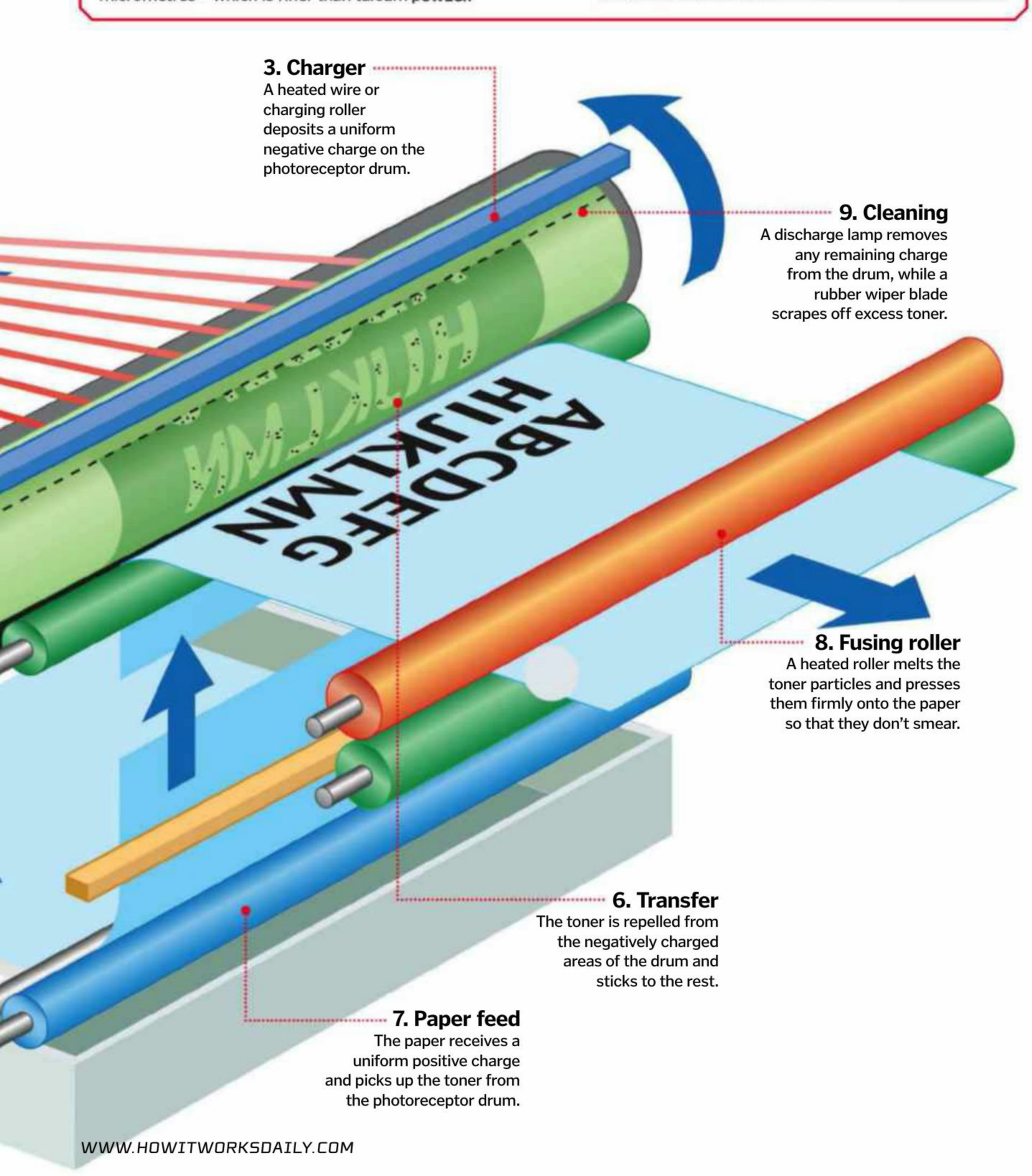
2010 Restrictions are placed on toner cartridges on US flights after laser printers filled with explosives are discovered.

DID YOU KNOW? *Many colour laser printers add tiny patterns of almost invisible yellow dots to watermark printouts*

What is toner?

Toner is more than just dry ink. It's a precise mixture of pigment and a special polymer such as styrene acrylate copolymer or polyester resin. The polymer boasts a property known as triboelectricity – this means it generates an electric charge when it is rubbed. As the drum in the toner cartridge rotates, the toner particles are jostled against one another and become charged so that they adhere to the photoreceptor drum. The polymer is also what enables toner particles to stick to the paper. When the fusing roller heats the toner, the polymer melts and binds the pigment permanently. If you spill toner on your clothes you should only wash them in cold water; even a warm wash will lock in the stain. Different companies have their own formulations, but most 600 dpi (dots per inch) printers use toner particles of just eight to ten micrometres – which is finer than talcum powder.

With around 300 million toner cartridges thrown away every year, there is a big drive to encourage people to recycle them



What's the alternative?

1 Inkjet

The most common home printers are inkjets. The printhead uses a heating element or an electric charge to propel tiny droplets of water-soluble ink onto the page. This allows cheap photo-quality prints but they are prone to smudging.

2 Dye sublimation

A cellophane ribbon, as wide as the paper, contains panels of cyan, magenta and yellow in a repeating sequence. The printhead heats the ribbon to vaporise the dye and transfer it to the paper. It's quite expensive but produces naturalistic colour.

3 Solid ink

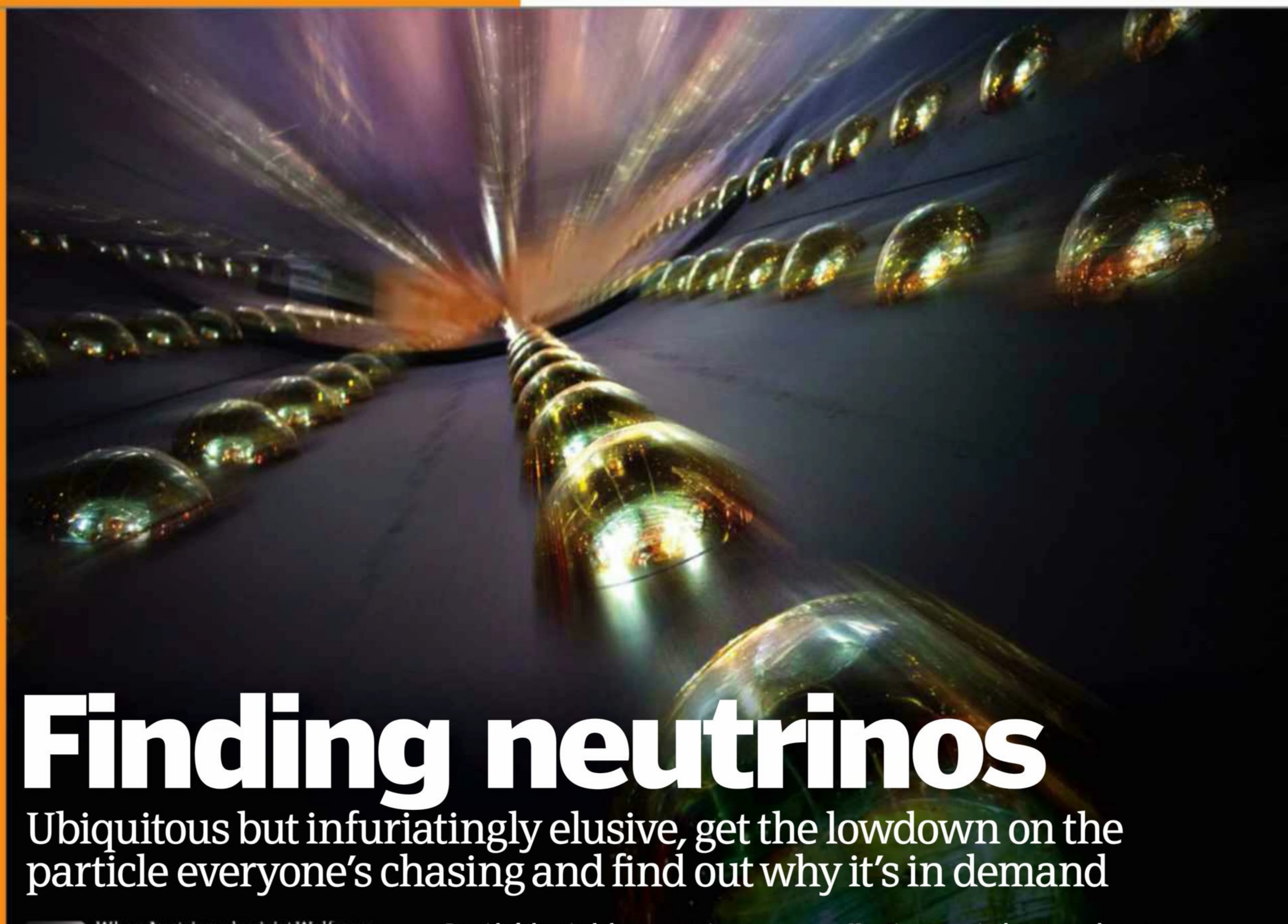
Solid wax sticks are melted and sprayed onto an oiled drum, which then presses against the paper. This process allows for colour prints on plastic transparencies with crisp results and costs about the same as a colour laser printer.

4 Thermal

Special thermal paper that changes colour when heated completely eliminates the need for separate ink. Commonly used to print till receipts, there are also colour versions for handheld printers used with mobile phones.

5 LED printer

Similar to a laser printer, except that a fixed bar of light-emitting diodes (LEDs) illuminates the entire row at once, instead of using a scanning laser. It is generally more reliable and faster too.



Finding neutrinos

Ubiquitous but infuriatingly elusive, get the lowdown on the particle everyone's chasing and find out why it's in demand

When Austrian physicist Wolfgang Pauli first predicted the neutrino's existence, he apologised for conceiving of a particle that he believed to be impossible to detect. Luckily he turned out to be wrong about this, but 80 years later this ghostly particle is still keeping scientists on their toes.

Neutrinos are subatomic particles produced in vast numbers during nuclear reactions, from the decay of radioactive elements to the fusion reactions that power the Sun. Given their diminutive size and lack of electrical charge, physicist Enrico Fermi named them 'little neutrons' – or, in Italian, neutrinos.

Indeed, a neutrino's mass is so tiny that for a long time most scientists suspected that it might not even have one. Although neutrinos still dodge attempts at precise measurement, their mass is now generally believed to be about a million times smaller than an electron's – in other words, next to nothing.

Devoid of electrical charge, neutrinos are oblivious to electromagnetic fields in their path as they race through the universe close to the speed of light. Their dealings with matter are limited to infrequent interactions through the weak force (which acts only over extremely short distances). As a result, although neutrinos are one of the most abundant particles in the universe, they remain notoriously difficult to detect, literally slipping through our fingers.

Discovering the neutrino was in itself a lengthy enterprise. In the 1920s, researchers observed that nuclear beta decay seemed to break the laws of conservation of energy. To resolve the problem, Pauli postulated the existence of a particle without charge and with virtually no mass. It was another 25 years before physicists pinned down the elusive neutrino. Since then, our understanding has come a long way, but they continue to provoke far more questions than answers.

Neutrinos come in three types, known as flavours: the electron neutrino, muon neutrino and tau neutrino. Each flavour is named according to the particle produced when it interacts with matter, and different sources of neutrinos churn out different flavours or combinations of flavours.

Studying electron neutrinos from the Sun in the Sixties, physicists were surprised to count only a third as many as expected. It appeared that most solar neutrinos vanished into thin air at some point during their journey to Earth.

The mystery was unravelled with the discovery that these nifty neutrinos had somehow transformed from one flavour into another. This shape-shifting trick – technically referred to as oscillation – defies our basic understanding of physics, sparking a revolution. Since then, various experiments have caught neutrinos in the act as they oscillate from one type to another.

5 TOP FACTS
LITTLE NEUTRONS

1 24/7 bombardment
50 billion of the Sun's neutrinos pass through your body every second. At lunch they shower down from above, but by night they travel through the Earth and come up under your feet.

2 Power in numbers
While individually they may be tiny, if you rounded up every single neutrino in existence, their collective mass would rival the joint mass of all the stars in the universe.

3 Speedy exit
Photons created in the Sun's core take thousands of years to get to the star's surface due to interactions with free electrons, but neutrinos whizz out in just over two seconds.

4 Bigger is better
IceCube is the world's largest neutrino detector, looking for interactions within a cubic kilometre of Antarctic ice. The South Pole's compacted ice makes it an ideal environment.

5 Nowhere to hide
The antineutrinos which are emitted by nuclear reactions could one day be used by drone aircraft to spot secret facilities that are producing nuclear weapons.

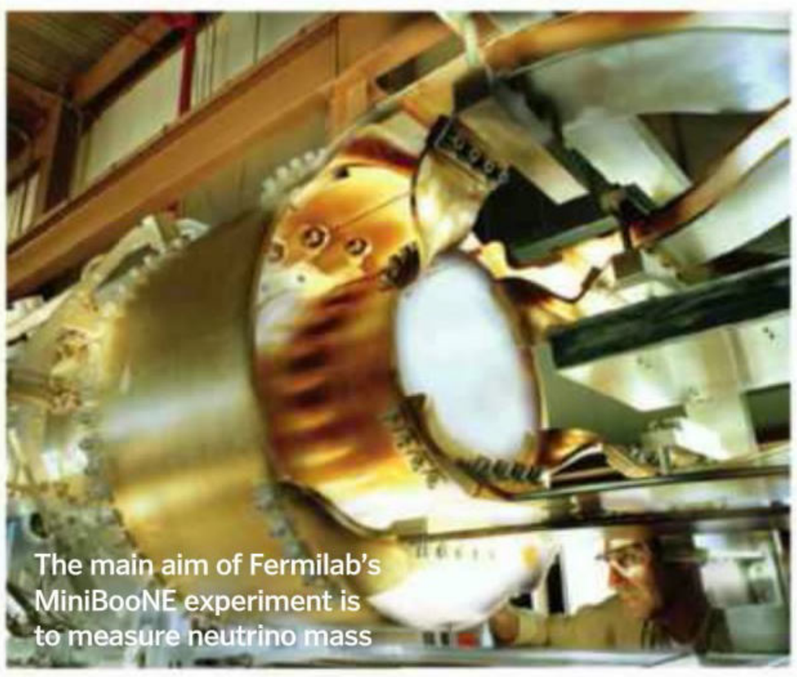
DID YOU KNOW? *A space the size of a sugar cube contains roughly 50 neutrinos left over from the early universe*

Upping the anti

All particles have an antimatter mirror image which resembles them save for a reversed electrical charge. Like their matter counterparts, antineutrinos are produced in nuclear reactions – eg the beta decay of radioactive isotopes. But as neutrinos have no charge, it's possible that neutrinos are their own antiparticle. If this is true then it will expose yet another flaw in the Standard Model and may help us work out how the neutrino acquires its minuscule mass. Experiments like the EXO-200 detector in the USA are scrutinising radioactive elements for a special type of beta decay to try and confirm this theory.

An engineer works on the MINOS experiment at Fermilab, Chicago, IL

A detector module at the IceCube Neutrino Observatory in Antarctica



The main aim of Fermilab's MiniBooNE experiment is to measure neutrino mass

Neutrinos continue to perplex scientists, but our limited understanding is certainly not due to a shortage of study subjects. The matter that makes up our world is constructed out of protons, neutrons and electrons, but for every proton in existence, there are about a billion neutrinos outnumbering it.

The majority of neutrinos in our universe were produced mere moments after the Big Bang, and those same neutrinos are still floating around to this day. More neutrinos are hurled across space by the nuclear fusion reactions taking place inside stars like our Sun, which blasts out over 200 trillion trillion trillion every second. The number of neutrinos created during a Sun-like star's lifetime, however, pales in comparison with the huge quantity spewed out during a supernova, the explosive death throes of a massive star.

Down on Earth, neutrinos are released by the fission reactions in nuclear power stations or nuclear bombs. As cosmic rays from outer space slam into our atmosphere, they also produce neutrinos. And finally, a small proportion of neutrinos are generated by determined scientists wielding particle accelerators.

Despite their abundance, neutrinos remain largely inscrutable. Most particle detectors track their targets thanks to their interactions with matter. Neutrinos, on the other hand, interact so rarely that the vast majority sail unnoticed through our planet without bumping into a single atom. When they do interact, they leave a charged particle such as an electron or muon in their wake. Spotting these ultra-rare events is the goal of neutrino detectors across the world, and it's no mean feat.

Building a detector of epic proportions is essential to maximise the chances of observing interactions within its confines. In Japan, the Super-Kamiokande III detector's hunting ground is a tank containing 50,000 tons of water ▶

Neutrino origins

1 Sun-like stars
Nuclear reactions fusing hydrogen into helium at the heart of our Sun produce 200 trillion trillion trillion neutrinos every second!

2 Supernovas
As a dying star collapses, it crushes protons and neutrons together, spewing phenomenal numbers of neutrinos of all flavours across the cosmos.

3 The Big Bang
The greatest ever source of neutrinos was the very birth of our universe. Many of these Big Bang relics are still around today.

4 Cosmic ray interactions
As high-energy particles from outer space enter our atmosphere, they smash into atomic nuclei, sending showers of muon and electron neutrinos cascading downward to the surface.

5 Nuclear reactors
The uranium and plutonium fission reactions inside nuclear power stations leave behind unstable radioactive isotopes. As these decay, they release electron-flavour antineutrinos.

"These unassuming particles have the potential to shake up the very foundations of physics"

(enough to fill about 30 Olympic-sized swimming pools) – yet it plays host to only eight atmospheric neutrino interactions a day.

Experiments probing neutrinos must also be shielded from cosmic rays and other types of radiation which can mimic a neutrino's fingerprint. As a result, disused mines are a prime location for labs, such as the Sudbury Neutrino Observatory (SNO) in Canada, buried two kilometres (1.2 miles) underground.

Once the scene is set for interactions, all that's needed is the right equipment to identify the products of a neutrino interaction. One common method currently employed is looking for specific patterns of Cherenkov radiation, a faint blue glow that is emitted when a charged particle travels faster than light itself passes through that same material.

The lengths which scientists will go to in exchange for just a fleeting peek at neutrinos may seem disproportionate, but these unassuming particles have the potential to shake up the very foundations of physics.

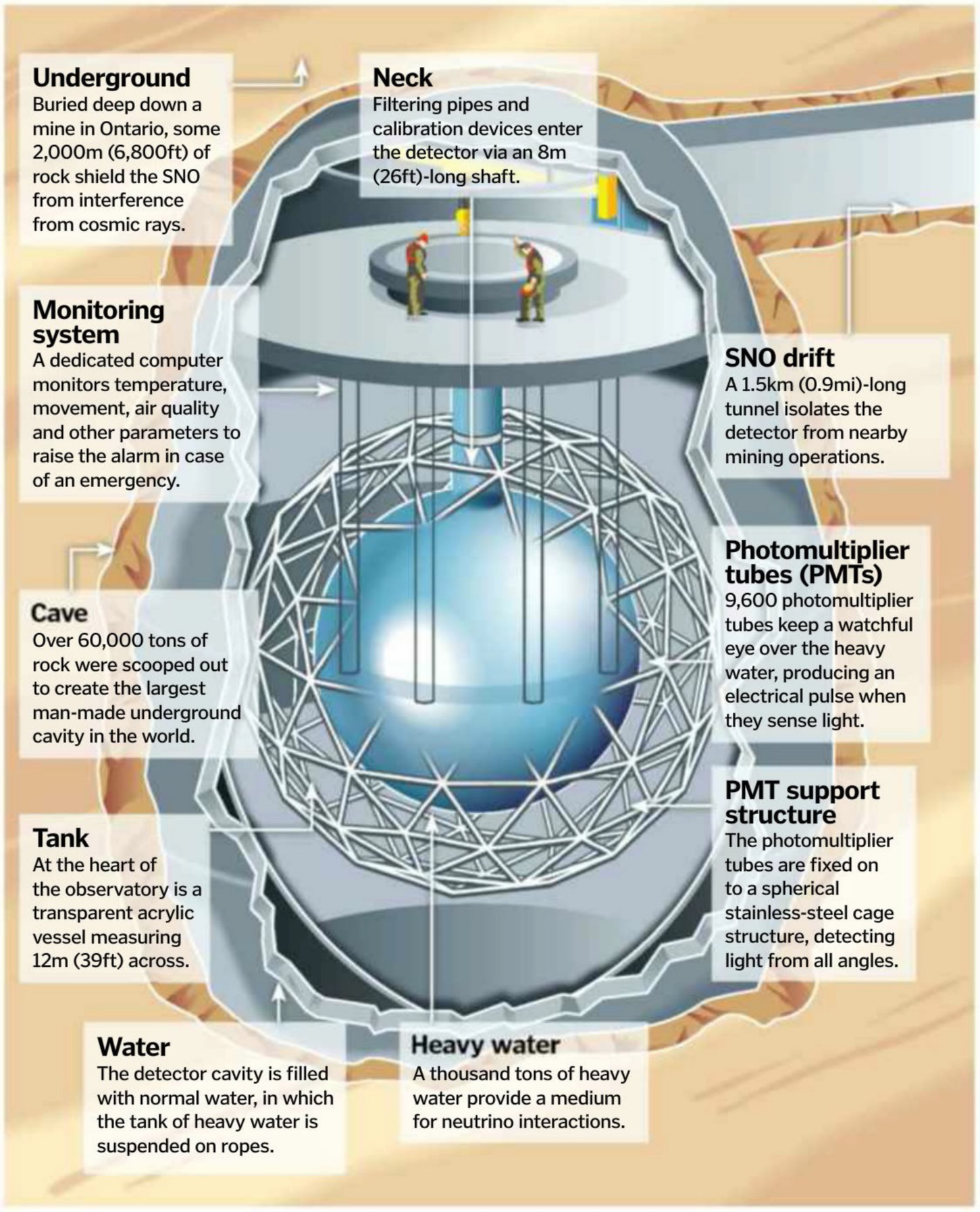
Although neutrinos have a place in the Standard Model – the framework that describes our current understanding of the universe on a subatomic scale – they take every opportunity to break the mould. The almost unfathomably small mass of neutrinos hints, for instance, that they don't acquire mass from the Higgs field like all other particles. Some also argue that they don't possess an antimatter twin like the other particles, but rather are their own antiparticles instead.

We're familiar with three neutrino flavours, but this neutrino family snapshot may be missing some key members. Several experiments have suggested the existence of 'sterile' neutrinos, so called because they don't even interact with matter through the weak force. These super-stealthy neutrinos might well be one of the ingredients of dark matter, the enigmatic substance estimated to occupy up to 80 per cent of the universe.

Many scientists believe that neutrinos could also shine light on the long-standing matter versus antimatter puzzle. According to current theories, matter and antimatter were created in equal parts during the Big Bang. Yet if this were the case, particles of matter and their antimatter twins should have crossed paths, annihilating each other on the spot. Our matter-dominated universe proves that something distorted this symmetry to favour matter over antimatter – a concept known as CP (charge parity) violation.

Tour of a neutrino observatory

Built in the Nineties, the Sudbury Neutrino Observatory (SNO) is currently being refurbished to refocus its sights on some of the latest questions in neutrino research. Baptised SNO+, the new detector will reuse much of its predecessor's infrastructure to hunt for the products of neutrino interactions but using a slightly different technique. Instead of heavy water, SNO+'s tank will be filled with a scintillator: a liquid that gives off light when charged particles pass through it. This will enable SNO+ to spot lower-energy neutrinos than before, broadening the scope of the facility's research.



Essentially, CP violation implies that the laws of physics are not the same for matter and antimatter. Nobody knows exactly how this might work, but scientists suspect that neutrinos may have been involved through something known as the 'seesaw mechanism'.

The theory goes that lightweight neutrinos were paired up with very heavy but transient particles in the early days of the cosmos. As these heavy particles disintegrated, they may have created the imbalance between matter and antimatter we see today. Observing differences in the way neutrinos and antineutrinos oscillate could validate the theory, and many consider this finding to be the 'holy grail' of neutrino research.

Fond of controversy, neutrinos are the ideal tour guides for scientists wanting a taste of what lies beyond the Standard Model. That said, one rule that rebellious neutrinos do

KEY DATES
NEUTRINO MILESTONES

1930 Wolfgang Pauli proposes the existence of a particle to solve the problem of missing energy in beta decay reactions.

1956 Fred Reines and Clyde Cowan observe neutrinos for the very first time next to a nuclear reactor.

1968 An experiment detecting solar neutrinos counts only a third of the expected number, a discrepancy known as the solar neutrino problem.

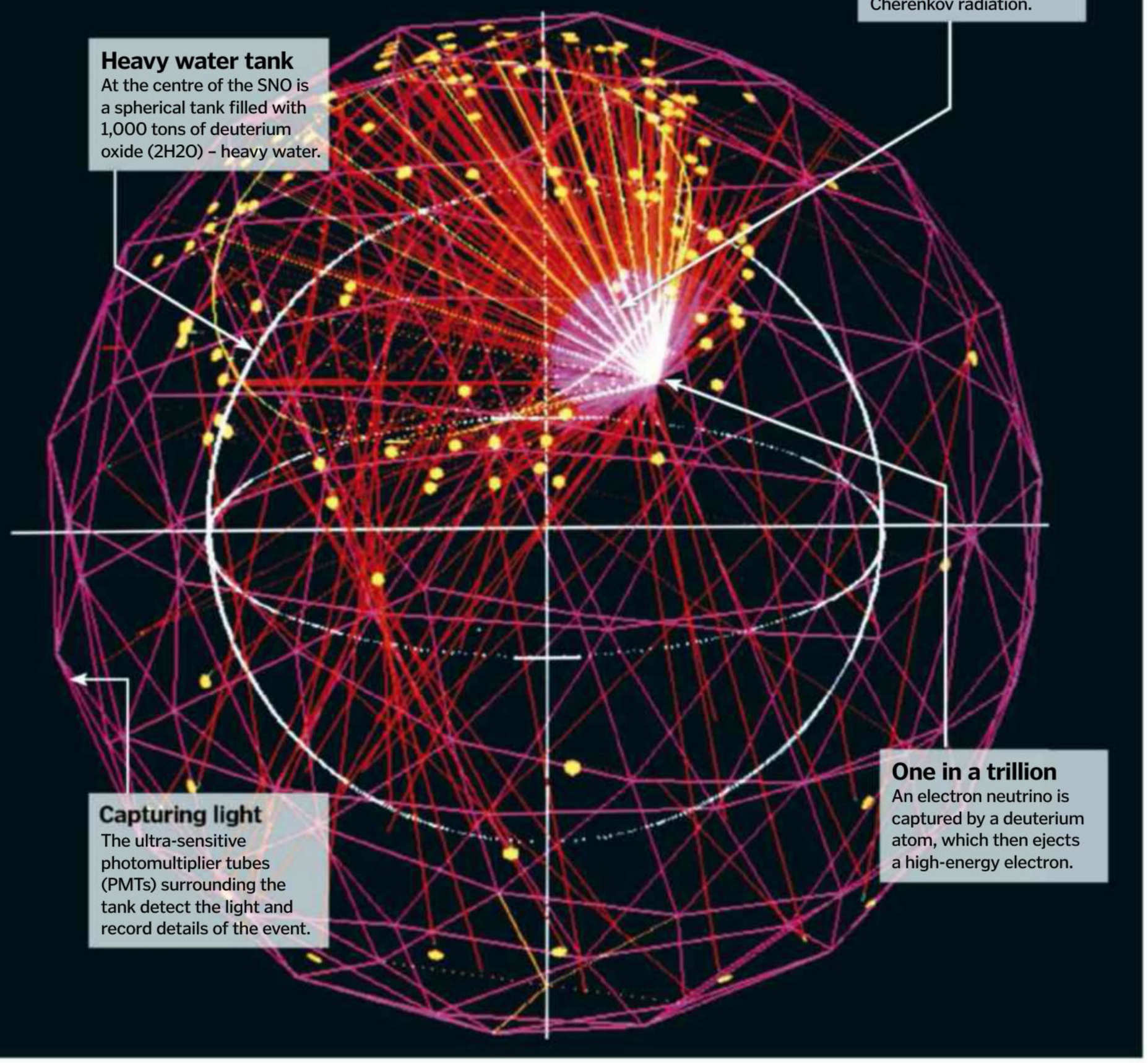
2000 The DONUT collaboration at Fermilab discovers the third member of the neutron family: the tau.

2001 The SNO provides conclusive evidence that neutrinos can morph into different types, resolving the solar neutrino problem.

DID YOU KNOW? *A neutrino could travel through lead for up to 22 years before colliding with one of its atoms*

Catch me if you can...

Of the trillions of solar neutrinos entering the Sudbury Neutrino Observatory's gigantic tank every day, only about ten make their mark on neutrino research. The three flavours of neutrino each interact with deuterium atoms in a slightly different manner, leaving a telltale electron which bears witness to their presence...



adhere to is the universe's speed limit – although in 2011 they briefly tricked scientists into thinking they had travelled faster than light thanks to a faulty connection.

Astronomers are also keen to get their hands on the humble neutrino. Travelling through space unimpeded, neutrinos can act as cosmic messengers, bearing information from all corners of the universe. Neutrinos could, for example, offer a glimpse inside the cores of distant stars, or the supernovas which created them. Likewise, neutrinos that were produced immediately after the Big Bang could even recount the universe's first baby steps.

Were Wolfgang Pauli still around, he would no doubt be amazed at the vast avenues of research opened up by his tiny particle. And with so much more left to uncover, it hopefully won't be long until the elusive neutrino gives up a few more of its well-kept secrets.

Neutrino hunters

1 Scintillators
Detectors like Japan's KamLAND (Kamioka Liquid Scintillator Antineutrino Detector) track down neutrinos with materials which emit a flash of light when struck by a particle. Certain signature flashes signpost collisions between neutrinos and protons.

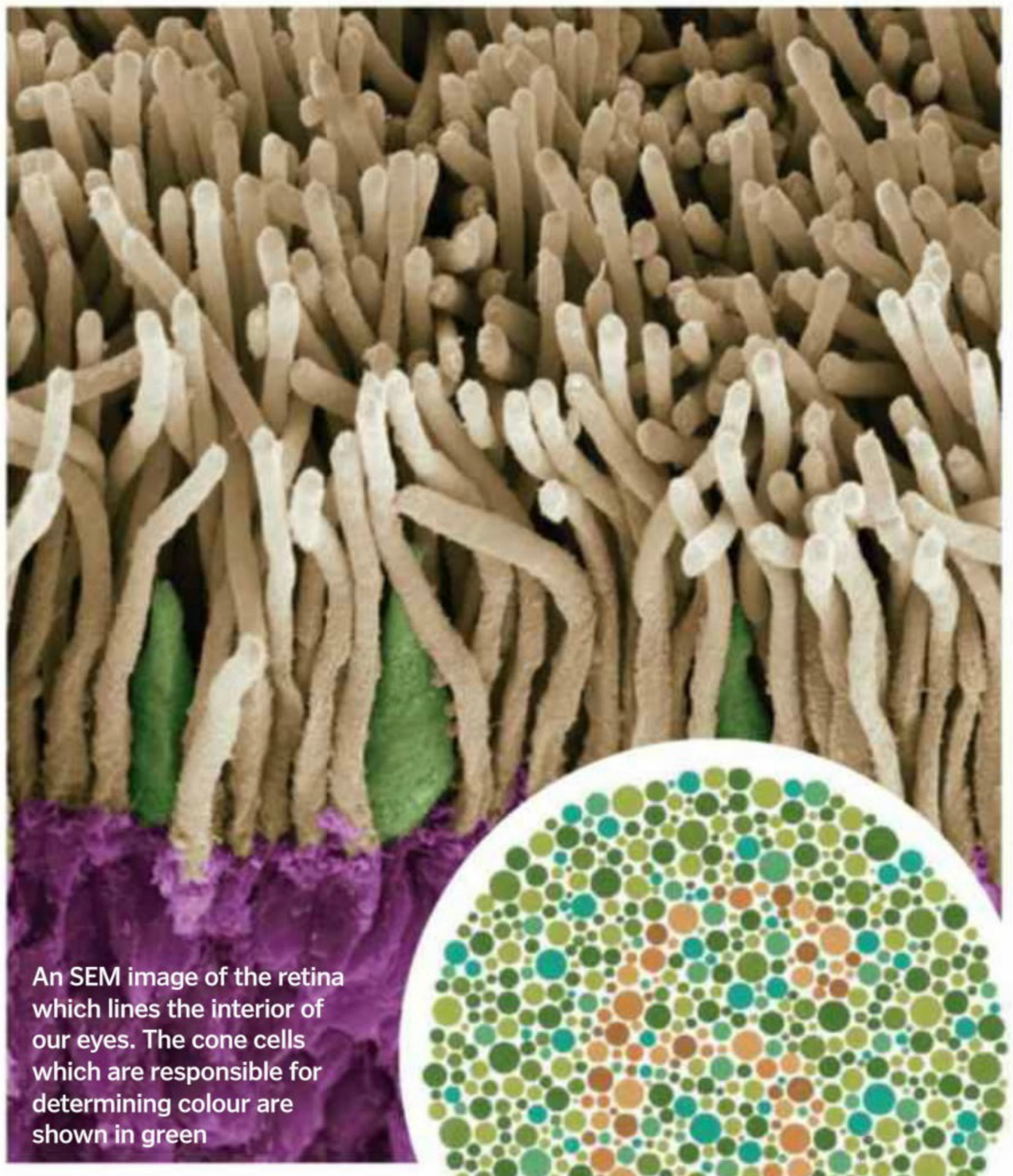
2 Radiochemical detectors
Incoming neutrinos can react with atoms – for example, converting gallium-71 into radioactive germanium-71 inside the GALLEX experiment which ran in the Nineties. Researchers then convert the amount of radiation measured into neutrino counts.

3 Cherenkov detectors
Detectors including Super-Kamiokande hunt for neutrinos by picking up the faint light that is given off by charged particles as they race through a special medium at breakneck speed.

4 Radio detectors
With antennas suspended by a helium balloon at 35,000m (114,830ft), radio detectors like ANITA capture the radio pulses emitted when high-energy neutrinos strike Antarctic ice.

5 Calorimeters
Useful for studying high-energy neutrinos produced by a particle accelerator, calorimeters such as the MINOS (Main Injector Neutrino Oscillation Search) experiment can track the particle debris resulting from neutrino interactions.

"Colour blindness is more common in men because most of the genes involved are on the X chromosome"



An SEM image of the retina which lines the interior of our eyes. The cone cells which are responsible for determining colour are shown in green

Can you see the number hidden here?

Colour blindness

Why do some people have trouble distinguishing between colours?

The human eye has three types of light-detecting cone cells, which contain pigments sensitive to different wavelengths of light: long (red), medium (green) and short (blue). The differences in the overlapping signals from all three are used by the brain to perceive colour.

Colour blindness occurs when one or more of the cone cells do not work properly. The most common form (which accounts for over 95 per cent of cases) affects perception of light at longer wavelengths, leading to difficulty distinguishing between red and green. Yellow-blue colour blindness occurs occasionally, and a few people can't see any colour at all.

Colour blindness is much more common in men than in women. This is because many of the genes involved in colour vision are found on the X chromosome. For a male (46, XY) a defect on his only X chromosome is sufficient to cause colour blindness, whereas for a female (46, XX) both X chromosomes must be defective – this latter scenario occurs much less frequently.

Research has shown that individuals unable to use colour to differentiate between objects develop superior visual skills with regard to identifying texture and shape. This enables them to see 'through' colour camouflage in a way that people with normal three-colour vision cannot.

How can plastic heal itself?

New materials can 'bleed' to repair themselves when they're damaged

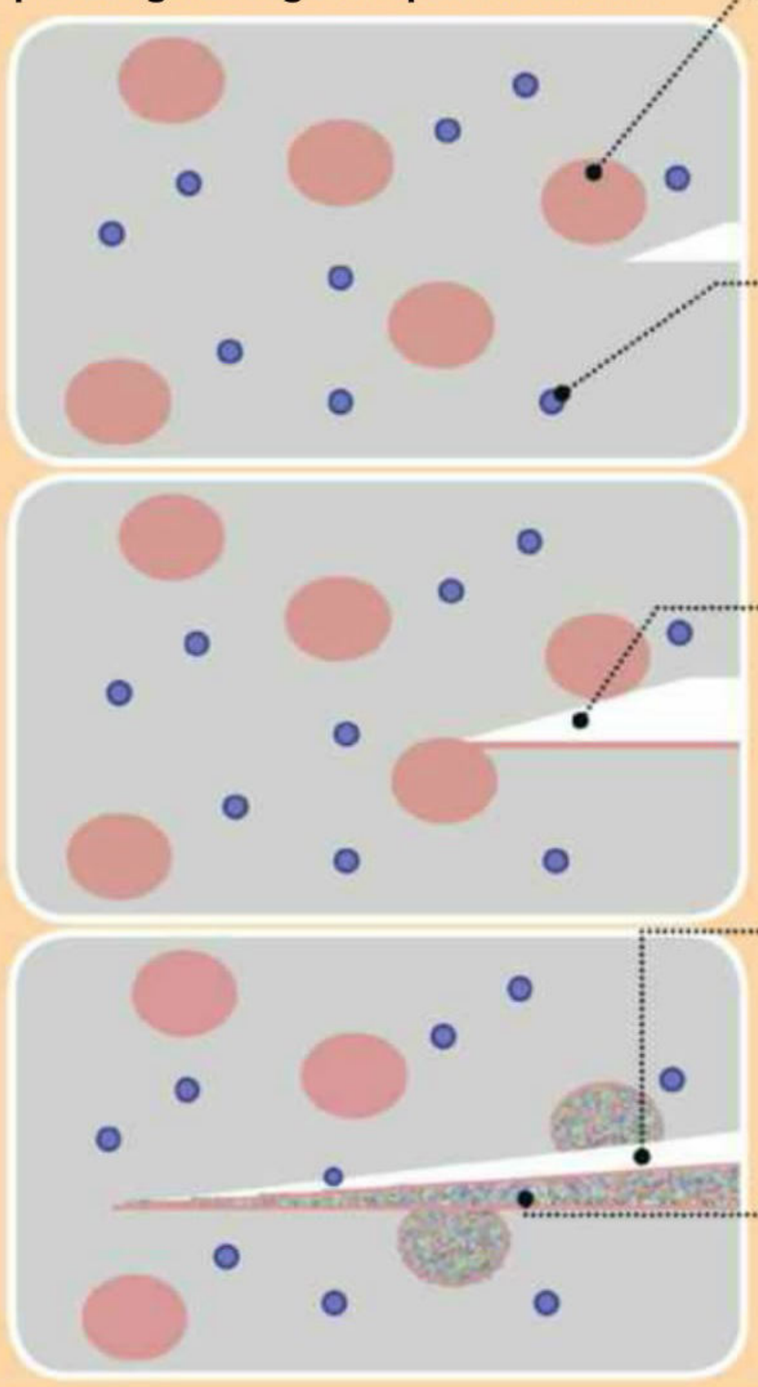
The simplest self-healing plastics incorporate microcapsules containing liquid resin and a separate catalyst. When cut open the capsules burst, releasing the material into the crack.

As it mixes with the catalyst the resin hardens, repairing the damage. This is effective for tiny cracks, but is limited because the more capsules you incorporate into the plastic, the weaker the overall structure becomes.

In order to create plastics that can heal larger cracks, scientists have borrowed ideas from biology and have created plastics with 'blood vessels'. By using a network of tiny channels, less than 0.1 millimetre (0.004 inches) in diameter, resin can be distributed throughout the plastic and delivered to the site of damage via the interconnected tubes. Some tubes contain the resin and others the hardening agent, and when the two are broken they mix to fill in the crack.

Microcapsule healing

Follow the process these sophisticated plastics go through to repair themselves



Microcapsule
Capsules of liquid epoxy resin are distributed throughout the plastic.

Catalyst
The epoxy hardener is kept separate from the resin.

Crack
As a crack starts in the plastic it punctures the microcapsules, and resin flows into the damaged area.

Mixing
The resin comes into contact with the catalyst in the crack, which begins a chemical reaction causing cross-linking.

Hardening
The epoxy cures (sets) within an hour, hardening and thus mending the damage.

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"Local anaesthetics provide a short-term blockade of nerve transmission"

How anaesthesia works

By interfering with nerve transmission these special drugs stop pain signals from reaching the brain during operations

Anaesthetics are a form of drug widely used to prevent pain associated with surgery. They fall into two main categories: local and general. Local anaesthetics can be either applied directly to the skin (as a cream, for example) or injected. They are used to numb small areas without affecting consciousness, so the patient will remain awake throughout a procedure.

Local anaesthetics provide a short-term blockade of nerve transmission, preventing sensory neurons from sending pain signals to the brain. Information is transmitted along nerves by the movement of sodium ions down a carefully maintained electrochemical gradient. Local anaesthetics cut off sodium channels, preventing the ions from travelling through the membrane and stopping electrical signals travelling along the nerve.

Local anaesthesia isn't specific to pain nerves, so it will also stop information passing from the brain to the muscles, causing temporary paralysis.

General anaesthetics, meanwhile, are inhaled and injected medications that act on the central nervous system (brain and spinal cord) to induce a temporary coma, causing unconsciousness, muscle relaxation, pain relief and amnesia.

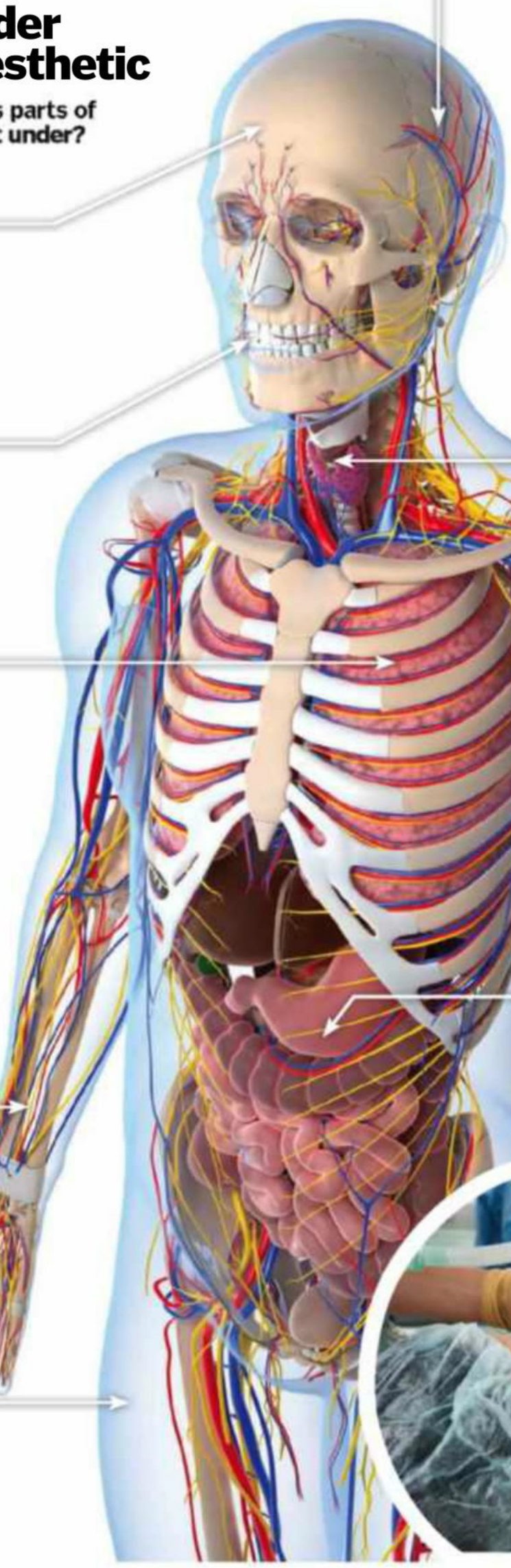
It's not known for sure how general anaesthetics 'shut down' the brain, but there are several proposed mechanisms. Many general anaesthetics dissolve in fats and are thought to interfere with the lipid membrane that surrounds nerve cells in the brain. They also disrupt neurotransmitter receptors, altering transmission of the chemical signals that let nerve cells communicate with one another.

Comfortably numb

If large areas need to be anaesthetised while the patient is still awake, local anaesthetics can be injected around bundles of nerves. By preventing transmission through a section of a large nerve, the signals from all of the smaller nerves that feed into it can't reach the brain. For example, injecting anaesthetic around the maxillary nerve will not only generate numbness in the roof of the mouth and all of the teeth on that side, but will stop nerve transmission from the nose and sinuses too. Local anaesthetics can also be injected into the epidural space in the spinal canal. This prevents nerve transmission through the spinal roots, blocking the transmission of information to the brain. The epidural procedure is often used to mollify pain during childbirth.

The body under general anaesthetic

What happens to various parts of the body when we're put under?



Memory
General anaesthetic affects the ability to form memories; the patient doesn't remember the operation and often won't recall coming to either.

Brain activity
Electroencephalograms (EEGs) show that the electrical activity in the brain drops to a state deeper than sleep, mimicking a coma.

Airway
Loss of consciousness and muscle relaxation suppress breathing and prevent coughing, so a tube and ventilator are used to maintain the airway.

Nil by mouth
General anaesthetics suppress the gag reflex and can cause vomiting, so to prevent choking patients must not eat before an operation.

Heart rate
The circulatory system is slowed by anaesthetic, so heart rate, blood pressure and blood oxygen are all continuously monitored.

Pain neurons
Unlike with local anaesthetic, pain neurons still fire under general anaesthesia, but the brain does not process the signals properly.

Nausea
Many anaesthetics cause nausea. Often antiemetic drugs that prevent vomiting are given after surgery.

Muscle relaxation
A muscle relaxant is often administered with the anaesthetic; this causes paralysis and enables lower doses of anaesthetic to be used.

© Getty

THE STATS
HMS HABBAKUK

LENGTH 610m WEIGHT **2mn tons** DEPTH 40m
CAPACITY **200 Spitfires** WIDTH 91m SPEED **7 knots**

DID YOU KNOW? *Pykrete can be made out of any kind of pulped wood, including sawdust and newspaper*

Bulletproof ice

Freezing a mixture of water and wood pulp leads to an unexpected result: ice as strong as concrete

During World War II a secret military operation, codenamed Habbakuk, set out to make a bulletproof aircraft carrier out of an unusual material: ice. This was no ordinary ice though; pykrete (named after the man who first conceived of Project Habbakuk, Geoffrey Pyke) is 10-20 per cent wood/paper pulp with the remainder made up of water, and incredibly it is bulletproof.

The ability of materials to resist gunfire is related to how effectively they absorb and distribute the energy of the impact. Ice is brittle and shatters when struck, however the flexible cellulose fibres in wood allow pykrete to soak up force much more effectively. As well as bullets, it can also deflect other impacts with a strength comparable to concrete.

As a building material, pykrete is very versatile. It can be machined to form shapes or cast like metal – and because it's less dense than water it floats. However, like ice, if large structures are constructed from pykrete, they are susceptible to 'creep'. Ice is held together by weak hydrogen bonds between stacked water molecules. If the block of ice is large, pressure can break the hydrogen bonds causing the molecules to slide over one another, leading to gradual deformation. Cooling pykrete to -16 degrees Celsius (3.2 degrees Fahrenheit), or using steel supports, helps to prevent creep though.

Pykrete has a higher melting temperature than water ice because the wood decreases its ability to conduct heat. Also, when it starts to melt, the wood pulp forms an insulating shell around the frozen core, slowing down the thawing process further.

Pykrete has also been used to build more practical structures like bridges

© Getty; Alamy

The awesome power of custard

Custard is a shear-thickening fluid (STF), which means that, when put under pressure, it turns rigid. You can see this in action at home. First, mix custard powder, or corn flour, with water to make a thick paste. If you take it out of the bowl and roll it in your hands you can make a ball, but stop applying pressure and it will return to liquid.

Liquids with these properties are being developed to replace bulky Kevlar armour. As a bullet strikes, the molecules lock together and the liquid thickens, absorbing the impact and halting the projectile's progress. Liquid body armour would be lighter, thinner and more flexible, enabling soldiers to move more freely and providing better protection under gunfire.

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KEY DATES
STOMACH ULCERS

1900s
Stress and diet are blamed for stomach ulcers. Patients are prescribed rest and bland food, like oatmeal.

1970
Stomach acid is proposed as the cause of gastric ulcers and antacid treatment is introduced to counter it.

1982
Two Australian scientists show that H pylori causes stomach ulcers, but some are sceptical to begin.

1996
The first antibiotics are approved for treatment of the infection that causes stomach ulcers.

2005
Barry Marshall and Robin Warren are awarded a joint Nobel prize for their 1982 discovery.

DID YOU KNOW? *The scientists who revealed bacteria caused gastric ulcers had to drink their own experiment to prove it!*

What causes stomach ulcers?

Originally thought to be the result of stress, we now know that bacteria are the culprits...

Normally a thick layer of alkaline mucus effectively protects the cells lining the stomach from the low pH of stomach acid. If this mucus becomes disrupted, however, acid comes into contact with the organ's lining, damaging the cells and resulting in an ulcer.

Around 60 per cent of stomach ulcers are caused by inflammation due to chronic infection by the bacterium Helicobacter pylori. Bacterial by-products damage the cells lining the stomach, causing a breakdown of the top layers of tissue.

Non-steroidal anti-inflammatory drugs (NSAIDs), like ibuprofen and aspirin, also cause stomach ulcers in large doses. They disrupt the enzymes responsible for mucus production, diminishing the protective barrier.

An ulcer in the making

Once bacteria breach the stomach lining, it can no longer protect itself from its acidic contents...

Neutralising stomach acid
H pylori break down urea to make ammonia. This is used to produce bicarbonate to neutralise dangerous stomach acid.

Ammonia
The ammonia made by the bacteria as a defence against acid damages the cells lining the stomach, causing inflammation.

Enzymes
H pylori produce proteases and phospholipases – enzymes that damage the proteins and cell membranes of the stomach cells.

Helicobacter pylori
Bacteria burrow through the mucus in the stomach to escape damage by acid. They stick strongly to the cells of the interior lining.

Gastrin
The inflammatory response increases production of the hormone gastrin. This in turn stimulates the formation of more stomach acid.

Damage
As the cells become damaged a wound opens up in the stomach wall. If this becomes deep enough it can perforate blood vessels causing bleeding.

Understanding vitamins

Find out about the vital nutrients required for the body to function properly

Vitamins are organic chemical compounds required in small amounts for essential functions throughout the human body. With the exception of vitamin D, they can't be made in the body itself so must come from our diet.

The recommended daily intake of vitamins is based on the average amount required for the majority of the population, but it varies depending on age, sex and lifestyle. For instance, post-menopausal women need more vitamin D to help guard against bone loss, while pregnant women need more of the B vitamin, folic acid, to prevent neural tube defects in the developing foetus.

Interestingly a balanced diet provides all of the vitamins that we need without requiring any supplements. Some foods, like cereal and bread, are fortified with vitamins as a public health measure to increase intake.

A balanced diet

Where can we obtain our vitamins and how can the body suffer if we don't get enough?

K
Vitamin K is involved in creating proteins that allow blood to clot. Not getting enough results in increased susceptibility to bleeding.

A
Vitamin A makes up part of the light-sensitive cells in the eye. A lack of this vitamin results in night blindness as sensitivity to light decreases.

E
Vitamin E scavenges free radicals, acting as an antioxidant. Deficiency is very rare, but can cause anaemia in newborn infants.

B
The B vitamins have important roles in metabolism and energy production. Deficiencies cause a range of diseases from anaemia to nerve problems.

D
Vitamin D is involved in maintaining calcium balance in the bones. Too little vitamin D in childhood prevents proper bone formation, causing rickets.

C
Vitamin C is essential for collagen production. Deficiency damages the skin and mucous membranes, which can lead to scurvy.

"Lymphocytes make 'memory' cells specific to the pathogen that remain in the circulation for many years"

How does the body's immune system adapt?

A highly targeted defence force patrols our bodies which not only destroys pathogens, but also remembers them for the future

The innate immune system is the first line of defence against pathogens. It provides rapid protection, trapping foreign invaders, coating them in toxic chemicals, engulfing them and digesting their remains. Though highly effective, its protection is not tailored to specific invaders, and it has no way to remember what it has fought before.

This is where the adaptive, or acquired, immune system comes in. Every pathogen is covered in signature patterns (antigens) that can be exploited by the immune system to launch a targeted attack. T-cells and B-cells – ie lymphocytes – are able to recognise antigens using receptors on their cell surface. Random shuffling of genetic material generates unique antigen-detecting receptors in every cell, allowing each of the millions of lymphocytes to recognise a unique antigen. This means that whatever infection the body faces, there should always be a lymphocyte that can respond.

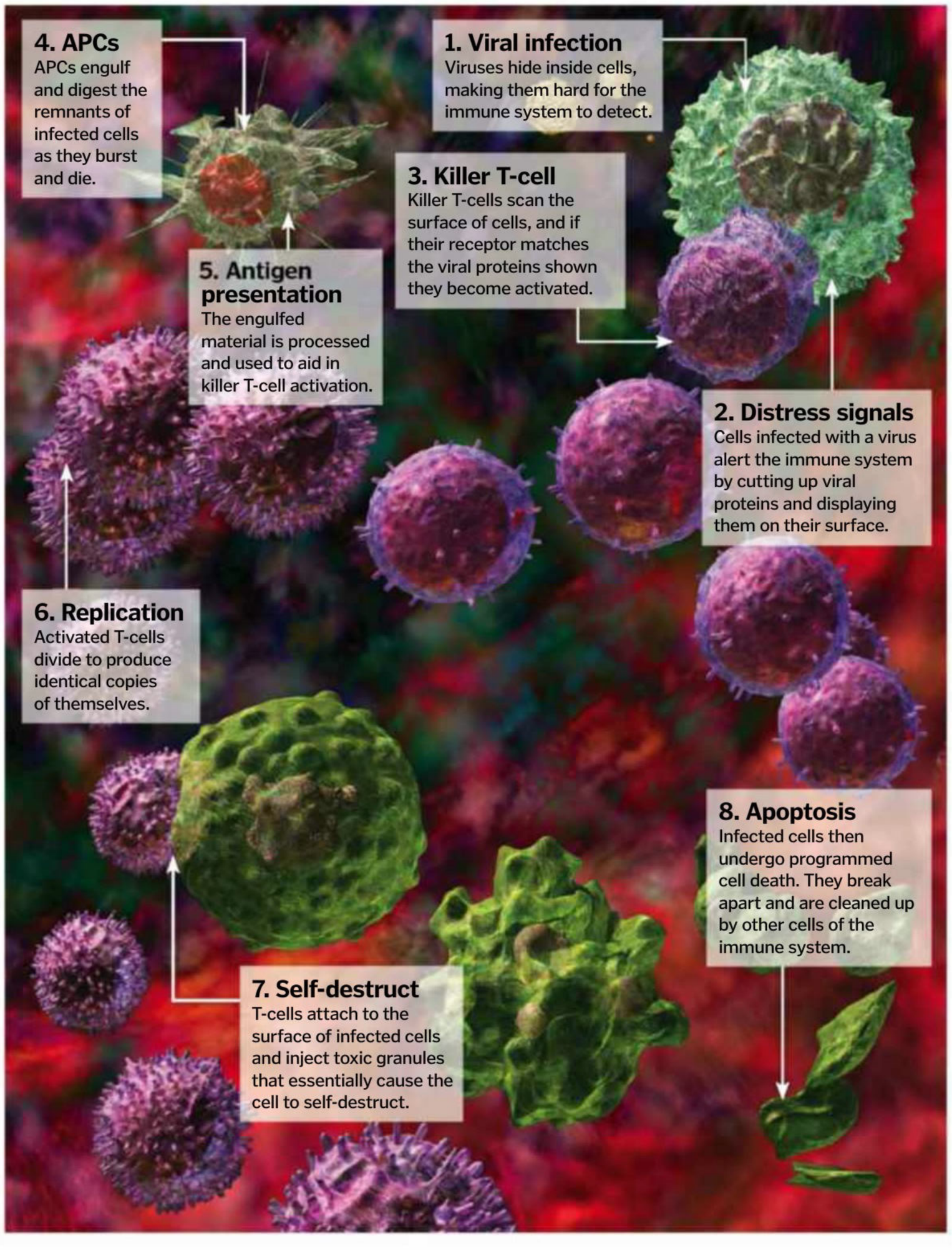
B-cells recognise antigens directly on the surface of pathogens, but T-cell targets often hide within human cells out of sight. Antigen-presenting cells (APCs) cut pathogens into fragments, which they then display for T-cells to examine. They also produce a cocktail of signalling molecules describing the location of the infection and the type of response needed.

Each person has millions of lymphocytes, so for any one pathogen there may only be a handful of cells with receptors that match the specific antigens. In order to make an army large enough to take down the invader, lymphocytes activated by their antigen divide rapidly to generate thousands more cells. This takes up to a week, during which time the innate immune system holds down the fort, keeping the infection at a manageable level.

While lymphocytes are dividing they also make 'memory' cells specific to the pathogen that remain in the circulation for many years. If the pathogen returns, these reactivate and start to divide, often reacting so quickly that the pathogen is killed before it can cause illness.

Vanquishing viruses

Infected cells are programmed to self-destruct to take out viruses hiding within



5 TOP FACTS
IMMUNE SYSTEM

1 Immunity smells
People are more attracted to the smell of those whose immune system differs from their own. People with rare genes in their immune system are the most attractive of all.

2 Pus is dead cells
Pus is the remains of cells that died while trying to consume pathogens. The dead cells are what give pus its whitish colour, while the yellow-green tinge is antibacterial proteins.

3 Cancer hides
The immune system can destroy cancer, but tumours have evolved advanced mechanisms to keep immune cells out and to prevent them from working properly.

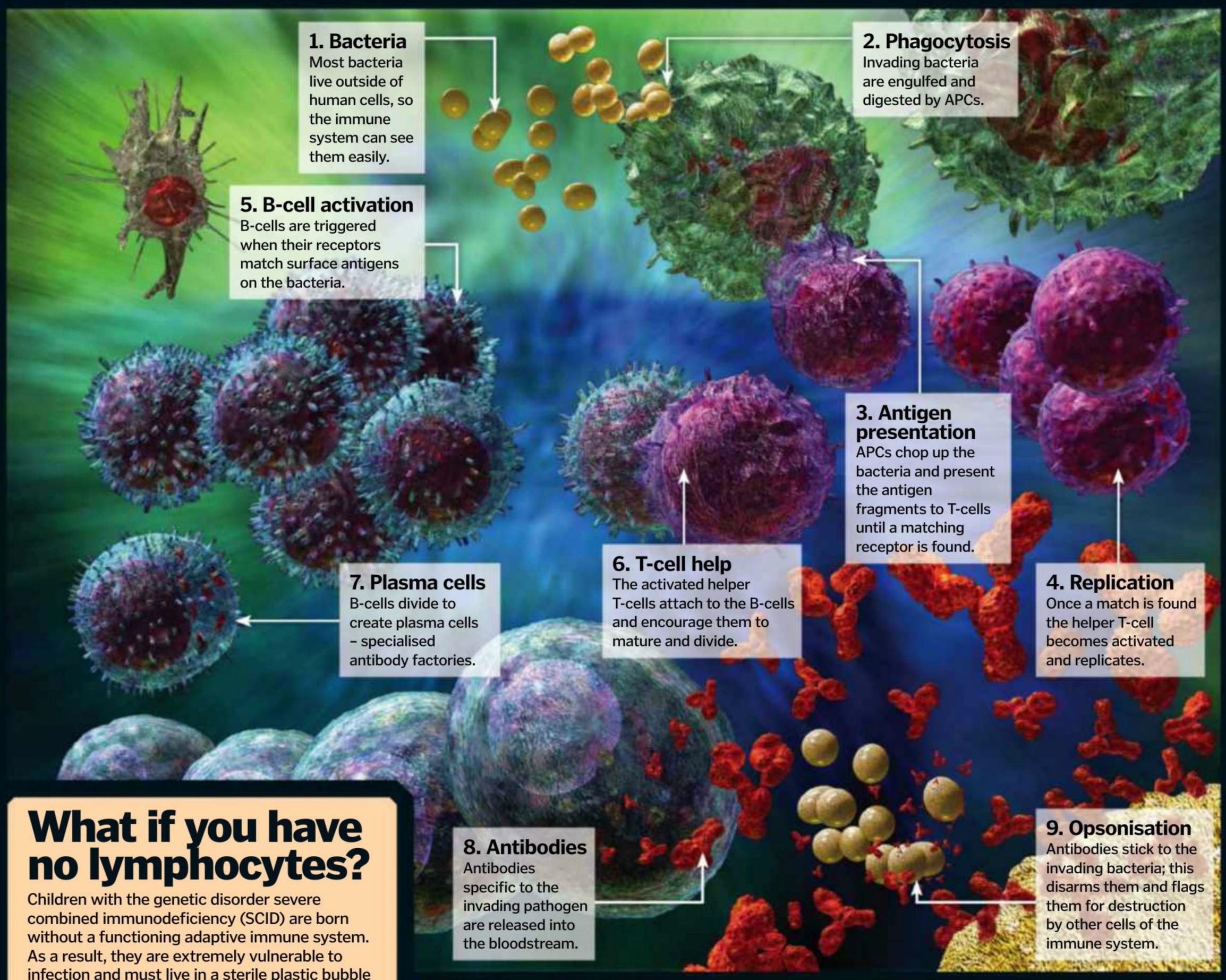
4 Renegade lymphocytes
If the immune system fails to distinguish between 'self' and 'non-self' it can attack healthy human tissue with the same persistence and ferocity with which it fights pathogens.

5 Breast milk is a vaccine
Breast milk has antibodies which enter the bloodstream of newborns and provide temporary protection from infection, though this only lasts for a few days.

DID YOU KNOW? *A recent study suggests that women's slower-ageing immune systems help them to live longer than men*

Battling bacteria

Antibodies are the main defence against pathogens that live outside human cells



What if you have no lymphocytes?

Children with the genetic disorder severe combined immunodeficiency (SCID) are born without a functioning adaptive immune system. As a result, they are extremely vulnerable to infection and must live in a sterile plastic bubble until their immune system can be replaced by bone marrow transplant. NASA even built a spacesuit for one child with this disease, David Vetter (pictured), which allowed him to venture a few metres outside without risking his health.

Similar vulnerability to pathogens is observed in patients with HIV/AIDS, who often die as a result of infection due to a lack of T-cells.

Vaccination and immunological memory

Immunity can be induced artificially through vaccination. Vaccines contain dead, or deactivated, bacteria and viruses; these don't cause disease, but still trigger the adaptive immune response, generating memory cells. If the live pathogen is encountered in the future, the memory cells will rapidly divide and the acquired immune system will be able to respond immediately, preventing illness.

MONSTER TRUCKS

What powers massive trucks that can drive over almost anything?

The phenomenon of monster trucking is a relatively new one. American 4x4 enthusiast Bob Chandler is credited with creating the first monster truck in 1974 when he raised the suspension on his Ford F-250 pick-up truck and fitted it with 122cm (48") tyres. He then attempted to traverse over two scrap cars in the vehicle, and was surprised at just how easily the truck accomplished the task. A legend was duly born.

Bigfoot #1, as it became known, was in fact a stock pick-up truck, with a beefier frame and engine later added to complement the changes in ride height and wheel size. Weighing a monumental 5,000kg (11,00lb), Bigfoot #1 wowed the crowds with its original stunts of driving straight over and squashing conventional cars.

Despite these early revelations of newfound motoring entertainment, vast improvements in the build were needed to prolong the life of a monster truck. This led to a new, more durable design being implemented.

By the mid-1980s, monster trucks used stronger axle housings with 'planetary gears' in the hubs to help turn the wheels and reduce stresses and axle-shaft breakage. Planetary gears work by a main gear in the middle (called a sun) engaging with three surrounding gears (called planets) at the same time. Once engaged, the planets rotate around the sun, running along the inside of a ring, giving a three-to-one gear reduction ratio.

These vehicles, now called 'stage two' trucks, also received heavier frames and axles taken from larger vehicles – but the chassis couldn't handle the extra weight. What's more, a stage-two truck now weighed around 6,800kg ▶

Firestarter

The Firestarter is a mini monster truck with all the characteristics of a full-scale one. It has the body of a 1940s fire truck and a working V6 engine.

Bigfoot #1

Completed in 1979, Bob Chandler's Bigfoot #1 is officially the world's original monster truck, as accredited by Guinness World Records.

Bigfoot #5

Bigfoot #5 stands at a staggering 4.7m (15.4ft) tall, with its colossal tyres being double the size of those on standard monster trucks.

DID YOU KNOW? *Many monster-truck owners shave down the rubber tread on tyres, saving around 90kg (200lb) per tyre*

Monster trucks by the numbers

2,000bhp
can be produced by a monster truck engine

10psi is the average tyre pressure for a monster truck

$120,000
is the annual cost of running and maintaining a monster truck

168cm is the average tyre height of a one of these trucks

112,650km
is the distance Monster Jam's truck drivers will cover per year travelling the globe for shows

9,423cm³
is the average size of the displacement of a monster truck's engine

65.5m
is the world record jump for a monster truck, recorded in 2012 by Bigfoot #18

91cm is the amount of 'wheel travel' nitrogen shock absorbers allow stage-three trucks

25 scrap cars are crushed by Monster Jam trucks in a typical show

Born from an idea in 1974, monster trucks have since taken motorsport by storm

Size matters

	Monster truck	Family saloon	London Bus	Smart car	Motorbike
Length	6m	4.8m	10.9m	2.6m	2m
Width	3.6m	1.9m	2.6m	1.6m	0.7m
Height	3.6m	1.5m	4.4m	1.5m	1.1m
Weight	4,500kg	2,210kg	8,119kg	820kg	170kg

"The chassis and frame are mounted high above the wheels, making it easier to traverse over large objects"

(15,000lb). They also operated the antiquated leaf springs as found on early cars, or spring packs that still offered a notoriously harsh ride with little travel in suspension. Inevitably during the early stages of racing competition, drivers often got hurt.

The third and latest evolution of monster-truck design has been the most significant. This incarnation cuts costs while improving performance, repair times and driver safety. Introduced in the early-1990s, the main development was in suspension: as a result, current monster trucks now use a series of nitrogen-charged shock absorbers, which compress under load and then expand substantially. Current shocks have around a metre (3.5 feet) of travel, cushioning the driver on impact with the ground from a big jump. Indeed, shocks can now handle the impact of landing a jump from up to 60m (200ft).

Modern monster trucks also use flotation tyres, usually intended for agricultural use. The tyres need to flex as part of the suspension, making low-pressure agricultural tyres ideal. Due to the volume of air that goes into a flotation tyre, monster trucks only need about 0.7 kilograms per square centimetre (ten pounds per square inch) of pressure per tyre.

As these trucks are seen as the brainchild of mid-western American petrolheads, it's only fitting that monster trucks are powered by another of America's greatest traditions: the V8 engine. Big Ford, Chrysler or General Motors engines are most commonly found in competitive monster trucks. Excessively tuned using superchargers and running on methanol, these engines can put down horsepower figures that hit quadruple figures. They can also catapult the five-ton vehicle to 97km/h (60mph) in under five seconds. Such rapid acceleration also helps the trucks make large jumps from relatively small ramps, throwing the front of the truck into the air when needed.

Despite such power, you're unlikely to find a manual gearbox anywhere near a meaty stage-three monster truck, with the vehicle instead running automatic transmission. Because the driver must contend with steering the truck while operating the accelerator and brake pedals, the presence of a third pedal in the clutch would prove an unwanted

Bigfoot: the original monster

Bigfoot is the first and most-famous monster truck. Chandler's original was retired in the mid-1980s, but he continued to name each of his many trucks since in numerical order – he's currently building Bigfoot #21

V8 engine
Textbook American muscle engines are favoured for their large capacity and ability to handle extreme power and stress.

Frame
The frame is tubular-welded for rigidity, helping the truck to handle and control better, and also protects the driver in case the vehicle is rolled.

Transmission
Two-speed transmissions are high mounted for maximum ground clearance.

Fibreglass shell
Monster trucks use a fibreglass shell as it's extremely lightweight and simple to repair.

Long-travel shocks
These nitrogen-charged shock absorbers have up to 1m (3.5ft) of travel to ensure a cushioned landing from big jumps.

Link bars
The four main bars that link the front and rear axles to the frame. They can be adjusted to control how much traction the truck can get.

Flotation tyres
Taken from agricultural machines, these make climbing objects easy and allow a cushioned landing afterwards.

AMAZING VIDEO! SCAN THE QR CODE FOR A QUICK LINK

Watch a montage of monster truck mayhem now!

www.howitworksdaily.com

DID YOU KNOW? *Monster trucks can float in water as the high volume of air in the tyres keeps the cab and engine afloat*

distraction. Many trucks today use two-speed transmissions, and besides, some automatic transmissions can allow drivers to shift up or down without the need for a pedal.

On the inside, a stage-three monster truck now also employs a complex tubular design made from steel and chromium-molybdenum for its frame and chassis, which strengthens the vehicle and protects the driver. This is where the conventional pick-up truck ends its association with monster trucks. Instead of using an 'original equipment manufacturer' body, each frame and chassis is custom built. The chassis and frame are mounted high above the wheels giving massive ground clearance, making it easier to traverse over large objects such as cars and allow for long travel from the suspension when landing a jump.

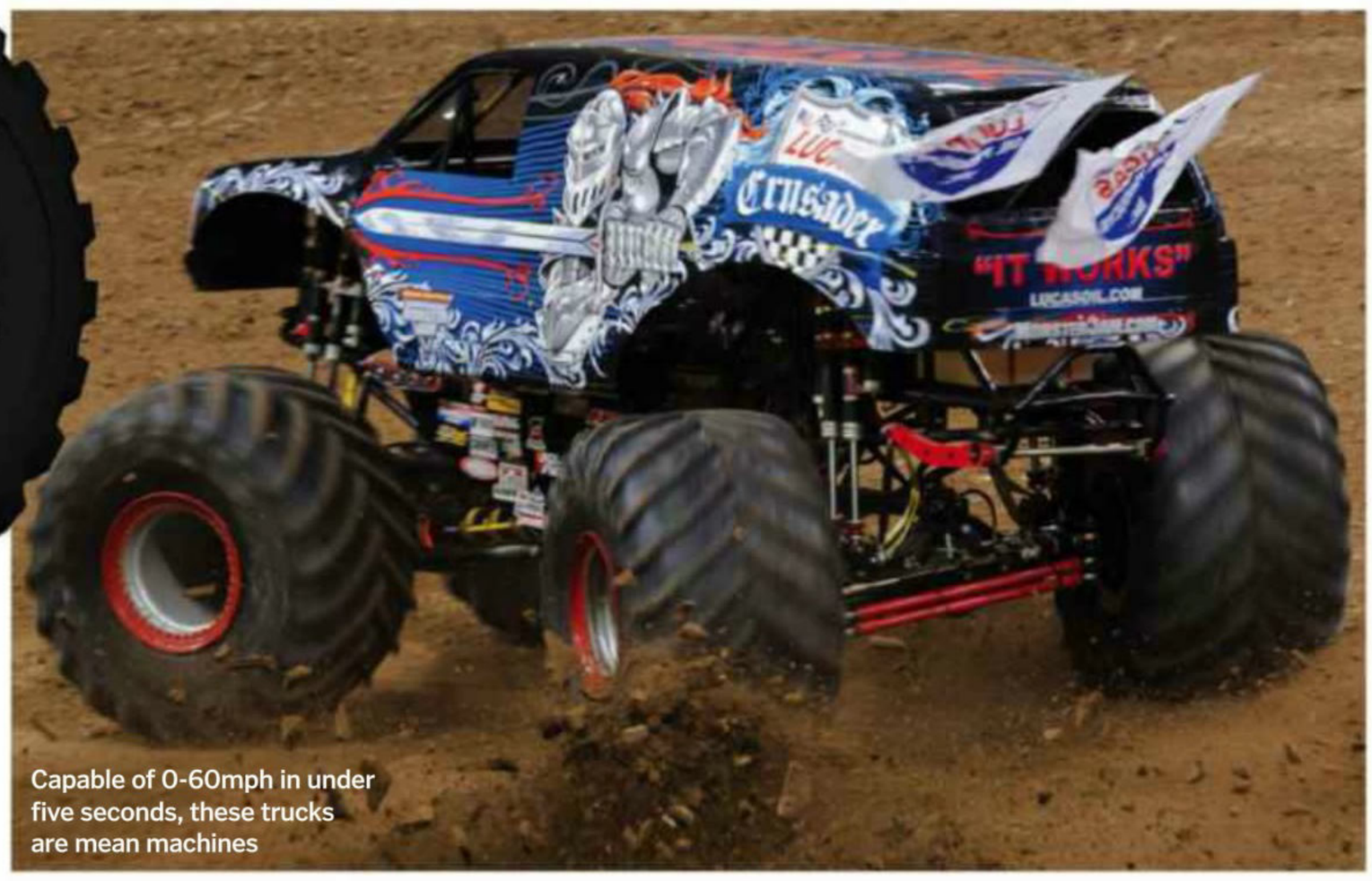
A lightweight and durable fibreglass shell then covers the frame and engine. Any lights, grilles and doors are merely decorative, saving further weight and ensuring the bodywork is easier to respray after repairs. Moving ever further from their ancestral pickups, some monster trucks are modelled on non-vehicular objects, such as Monster Mutt, or Batman, styled according to the famous superhero. With no conventional doors to climb in and out of the truck, the driver instead enters and exits via an escape hatch in the middle of the cockpit floor.

Monster trucks have traditionally followed the layout akin to that of a conventional American road vehicle, with a front-mounted engine and driving position to the left of the cabin. However, some of the more modern monster trucks now operate with the driver sitting in the middle of the cabin with a mid-mounted engine underneath. With more weight now in the centre, monster trucks enjoy greater balance, making them more nimble when performing stunts.

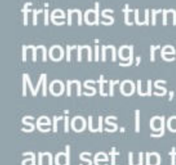
Front- and rear-wheel steering on today's trucks allows them to corner faster and gives the driver a few more valuable seconds to make a turn after coming down from a big jump.

A monster truck built for competition can take three months to a year to build. This depends on the intricacy of the tubular frame and the overall truck's design. Once built, a monster truck can dominate and even decimate a terrain littered with man-made objects thanks to its excessive weight and power. It may be loud, lairy and disproportionately scaled, but make no mistake: a monster truck is an engineering marvel.

As such, motorsport involving monster trucks is very popular. Many of America's top-end monster trucks take part in the world-famous Monster Jam, a globetrotting series in which experienced drivers perform sprint races and freestyle events to tens of thousands of spectators. A sprint race is a dash to the line between two trucks at a time, where the winner goes through to the next round until just one truck remains. The freestyle event, meanwhile, gives trucks around 90 seconds on the arena floor to dazzle three judges. Stunts typically include jumping up onto and then crushing cars, as well as performing sky wheelies and multiple doughnuts.



Capable of 0-60mph in under five seconds, these trucks are mean machines



Taming monsters

President of the Monster Truck Racing Association of Europe, Nigel Morris, talks about driving a Bigfoot

What's the personal appeal behind monster trucks for you?
My dad put me on a motorbike at the age of six, and I raced for years and did well. I then started racing jet-skis, and after one or two other sports I found my way to monster trucks – and it's more fun than anything I've done. It's a vehicle that measures (3.7x3.7x6m) 12x12x20ft, weighs five tons and does (0-100km/h) 0-62mph in under five seconds. What's not to like?

How did you get into monster trucking?
I was an ex-computer salesman who took a redundancy many years ago and set up a business building custom 4x4s for street use. Then sitting round the campfire late one night at a truck show, a good friend reckoned I could build a better monster truck than the one in action earlier that day. I told my friends we'd start next Saturday. Sure enough, four of my friends turned up at my workshop that Saturday morning, ready to work. We built my first truck, Monstrous, and things started to get more serious. I got in contact with the MTRA in the US and set up the European version of MTRA, of which I am now president.

How did Bigfoot #17, representing the Bigfoot monster truck in Europe, come about?
Liaising with the US put me in contact with Bigfoot owner Bob Chandler, who told me he wanted a truck based permanently in Europe. Bigfoot #17 was then built in Daventry, UK, and is largely identical to Bigfoots #9-15, with several updates over the years.

How does the monster-truck industry in Europe compare to the USA?
The industry in Europe is ten years behind the USA, mainly due to the arenas. In the USA, the Monster Jam arena is on a par with Wembley. We've performed on hockey pitch-sized arenas here. We therefore have to tailor what we do to fit the arena, so it's all about the environment.

What repairs and maintenance is needed?
It depends from show to show. These are expensive trucks, so while sometimes you only have to replenish oil filters and fuel, you may need an engine rebuilt which is approximately £15,000 ($22,800). I've known teams to go through five gearboxes a year.

What must the driver think about when performing a freestyle run?
It's all about control and reaction, and control is down to instinct. A monster truck is no different to operate than a car, other than the rear-axle steering that's controlled by your right hand. A driver thinks, 'What can I hit next that'll be dramatic?' and so you plan a rough route. A truck can do the same jump three times, but get a different landing each time. It's from there when a driver decides if he's going left or right.

"In Asia... monorails also play an important role in public transport around major metropolises"

How monorails work

How do these trains stay balanced on one rail – and even hover above it?

Monorails have been around since the 1800s, but only really came to public attention in the 1950s when Walt Disney installed one in his new theme park: Disneyland, California. In most parts of the world their use is still restricted to amusement parks, however in Asia – particularly Japan – they also play an important role in public transport around major metropolises.

Modern monorails are based on a single solid beam that supports and guides the train; the carriages are either suspended beneath the track, or sit on top, with their wheels straddling the beam. They are usually powered by electricity, which is carried on a 'third rail' either within, or connected to, the main beam. Conductive shoes on the carriages then transmit the current to the train.

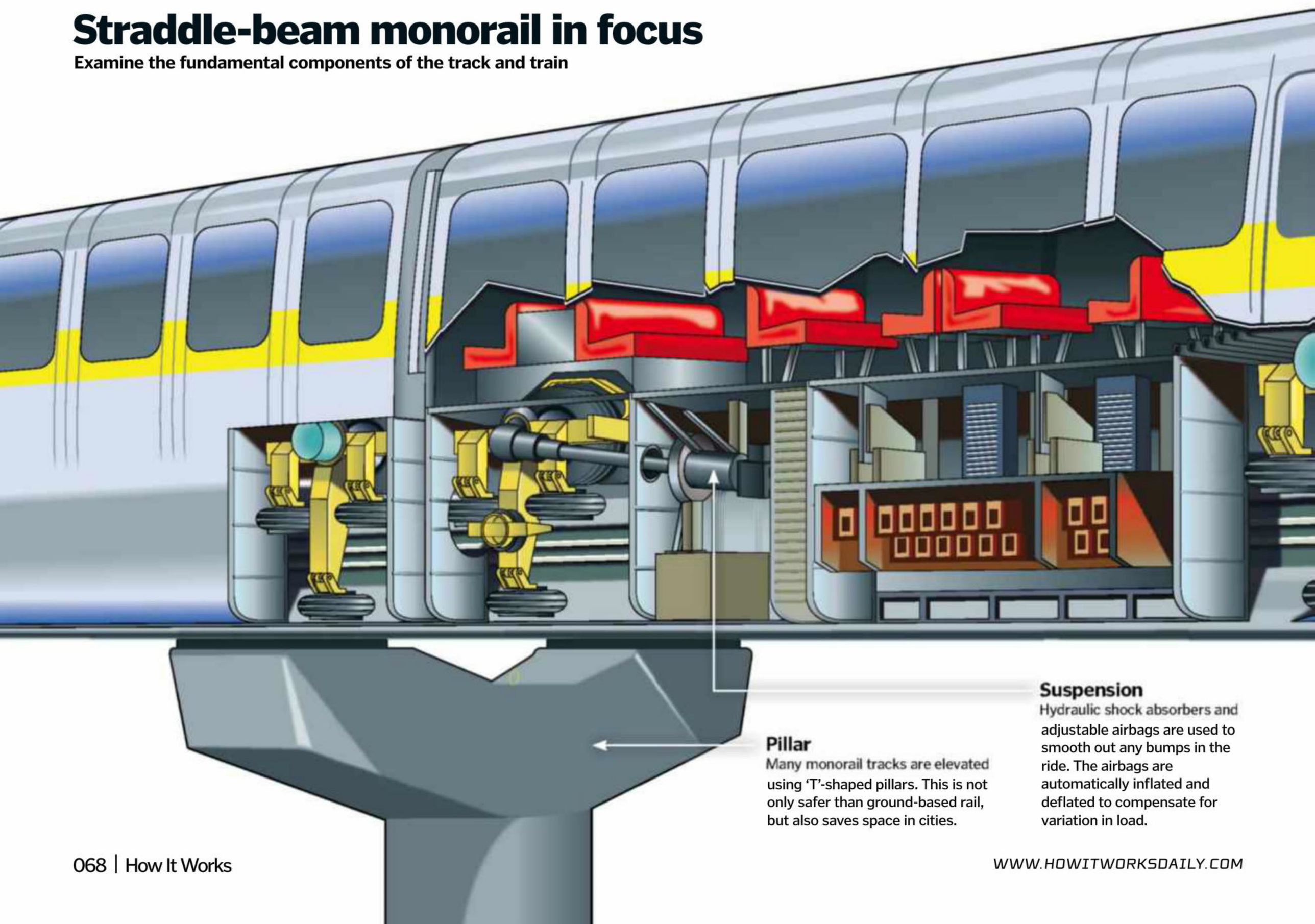
The straddle-beam design is the most widely used. The carriages have pneumatic rubber tyres, which drive along the top of an 'I'-shaped beam. To prevent side-to-side swaying of the train, a series of smaller tyres clamp around the beam, providing general stability and also helping to guide the carriages.

Suspended monorails, meanwhile, hang underneath the track. The design can be a simple inversion of the straddle monorail, where the cars hang from the underside of the 'I' beam, or alternatively the wheels can sit inside a hollow steel girder. In the latter case, the wheels are completely enclosed, protecting them from the elements and making the train extremely difficult to derail.

In fact, monorails are one of the safest forms of transport. The elevated track minimises interaction with traffic and pedestrians, eliminating the need for crossings, and derailment is very rare. They are energy efficient too and their rubber tyres produce much less noise pollution than the metal wheels of conventional trains.

Straddle-beam monorail in focus

Examine the fundamental components of the track and train



RECORD BREAKERS
PASSENGER PEAK

311,856

WORLD'S BUSIEST MONORAIL

The Tokyo Monorail has an elevated track that follows the coast of Tokyo Bay. Running at speeds of up to 80 kilometres (50 miles) per hour its trains carry nearly 312,000 passengers around the city a day.

DID YOU KNOW? *Monorail tracks aren't always elevated – some run along the ground like regular trains*

Types of monorail

Find out how careful arrangement of magnets can levitate monorail trains clean off their tracks

Electrodynamic levitation

Repulsion
Both the train and the track generate opposing magnetic fields, which repel each other, pushing the carriages upwards.

Electromagnetic levitation

Attraction
The carriages have arms extending underneath the track. Attraction between magnets on the track and the carriages lifts the train up.

Side magnets
Magnets at the sides are used to balance the train on the track.

Inductrack

Opposing fields
The magnets in the carriages induce opposing magnetic fields in coils of wire in the track, causing repulsion.

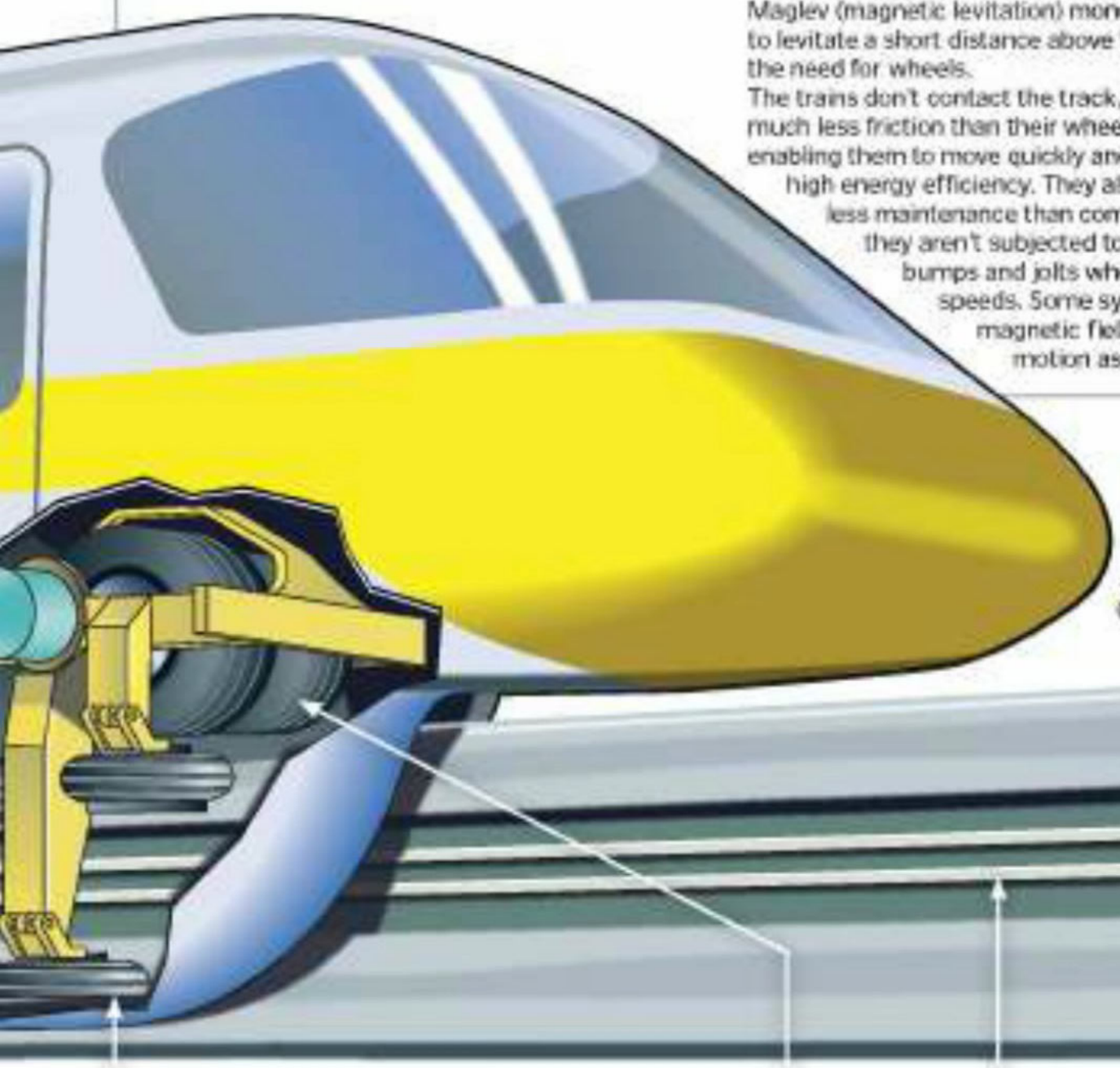
Magnetic propulsion
Permanent magnets on the train have a rotating pattern of magnetisation; as the magnetic field rotates it provides forward motion as well as levitation.

Up in the air...

Maglev (magnetic levitation) monorails use magnets to levitate a short distance above the track, removing the need for wheels.

The trains don't contact the track, so they experience much less friction than their wheeled counterparts, enabling them to move quickly and quietly, and with high energy efficiency. They also require much less maintenance than conventional trains as they aren't subjected to the same stresses, bumps and jolts when they reach high speeds. Some systems use rotating magnetic fields to provide motion as well as levitation.


The Transrapid in Shanghai has a design speed of over 500km/h (310mph)



Track
The track is made of steel or reinforced concrete and is about 0.6-0.9m (2-3ft) wide.

Guide wheel
Smaller wheels clamp the vertical edges of the track; these keep the carriages steady and guide the train along the track.

Drive wheel
The train is supported and propelled by a series of drive wheels on the underside of the carriages.

Electrified wires
Wires within the rail carry the electricity that powers the train; it is conducted to the carriages by contact points positioned beneath them.

The switch myth

Early designs for switching monorail trains from one track to another involved enormous rotating switches that were slow and cumbersome, and thus many monorails are built on a closed loop that requires no switching at all. This has led to the development of a myth that monorail switches don't work. However, modern straddle-beam transport systems employ segmented tracks, which allow short sections to bend smoothly and quickly, providing rapid track switching and taking up much less space than the bulky 360-degree switches of the past.

"Destructive interference is also used in noise-cancelling headphones and soundproofing"

How mufflers block out noise

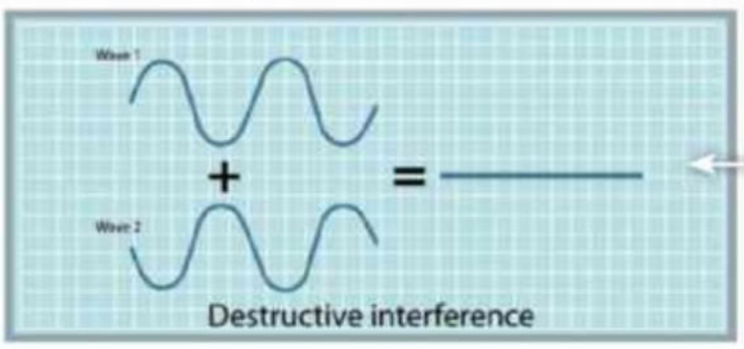
Discover how these harmonically tuned chambers are able to quieten noisy engines

Mufflers work on the principle that if two opposite sound waves collide they cancel each other out. This phenomenon, known as destructive interference, is also used in noise-cancelling headphones and soundproofing.

Sound waves create local changes in atmospheric pressure, which is why you can feel the bass thump if you stand close to a speaker. A collision between two sound waves that changes the pressure the same amount but in opposite directions will nullify both waves, silencing the noise.

Mufflers use a combination of complex tubing and chambers in order to bounce the sound waves and create opposites which will interfere with one another. The positioning of the holes, the distance between the walls of the chambers and the volume of air that the muffler holds are all carefully calibrated to offset sound waves at the frequency most used by the car engine.

Mufflers are fixed to a narrow set of frequencies, but cars produce a wide range of sounds, especially as they change speed. Mufflers are therefore also heavily insulated, providing physical noise dampening on top of destructive interference.



Muffler mechanics

Take a closer look at the tech that turns the roar of an engine to a purr

Interference
Holes in the muffler allow some sound waves through, while others are reflected, generating opposing waves.

Noise cancellation
As the opposing sound waves are deflected by the chamber they line up and cancel each other out.

Perforations
The tubes are also covered in tiny holes, which let more sound waves escape and interfere with one another.

Destructive interference
Two waves with opposite peaks and troughs in pressure offset each other when they meet.

Inlet
Exhaust gases and sound waves enter the muffler through an inlet tube.

Tuning
The muffler is designed so that the distance between the chambers matches the resonance of the sound waves.

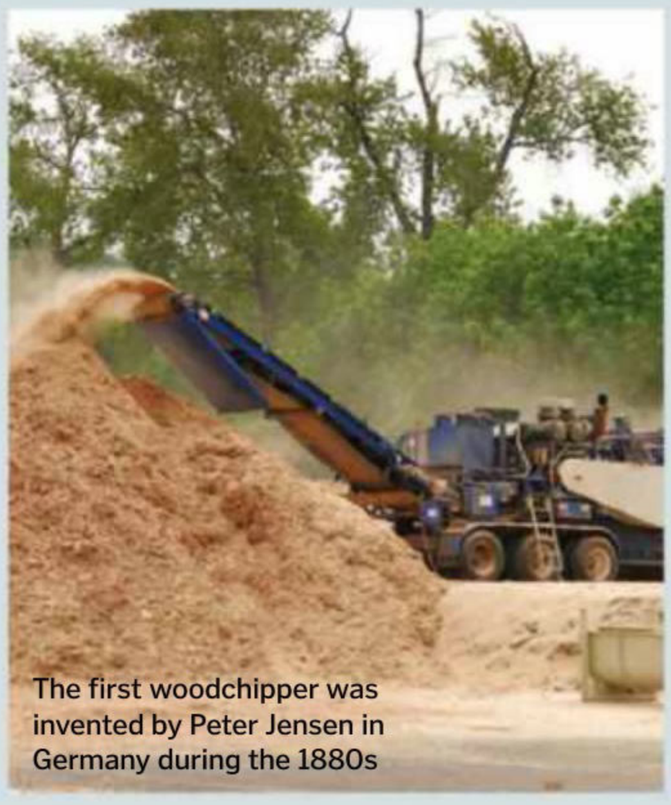
Woodchippers in focus

Find out about the technology that allows whole tree trunks to be converted into woodchips in a matter of seconds

Portable woodchippers are used to break logs into smaller chips for biofuel, manufacturing or recycling. There are three main components to the chipping machine: a hopper to feed the wood into the machine, a chipper mechanism and a collection bin.

The chipper mechanism is traditionally a rotating steel drum with reinforced steel blades along its length. The wood is drawn in by a combination of gravity and the rotation of the drum. Drum chippers rapidly break wood down, but are noisy and create large, uneven chips. Newer woodchippers use a steel flywheel instead of a drum. The wood is fed into the chipper on hydraulic rollers and blades on the face of the flywheel cut against a fixed anvil plate, producing uniform woodchips. Behind the disc are serrated paddles, which break down any bigger chips before the cut wood is ejected into a container.

Much larger 'whole tree chippers' have carbide flail hammers, which pulverise the wood by mechanical force rather than by cutting. These are very heavy and are usually towed by a truck.



The first woodchipper was invented by Peter Jensen in Germany during the 1880s

THE STATS
MOWER NUMBERS

NOISE 90dB

ANNUAL INJURIES **68,000**

FUEL USED PER YEAR (LITRES) 3,600mn

YEAR PATENTED **1830**

FUEL SPILT PER YEAR (LITRES) 77mn

NUMBER SOLD IN USA ANNUALLY **5mn**

DID YOU KNOW? *A lawnmower creates the same amount of pollution in an hour as 11 cars!*

Ride-on lawnmowers

Find out how these diesel-powered cutting machines which you can drive help keep huge sports fields and lawns neat and trim

Sit-on lawnmowers typically feature a diesel engine, which uses two drive belts: one to turn the wheels and one to turn the rotating blades. The controls are similar to a car's, with gears, pedals and a steering wheel.

Most ride-on mowers have a series of rotary steel blades; these spin horizontally across the ground, creating upwards suction, which draws in the grass. The spinning blade cuts the grass very roughly and can cause discolouration due to bruising and tearing. Controls allow blade height to be adjusted, so they can be lifted and disengaged from the engine while the vehicle is being driven.

For high-quality lawns, a reel mower is used instead. These have a fixed cutting bar, which is positioned parallel to the grass; as the mower moves over the lawn a series of spiral blades attached to a reel above the fixed blade spin rapidly, pushing the grass past the bar. The gap between the reel and the bar is kept at approximately the thickness of a blade of grass, which ensures a super-clean cut.

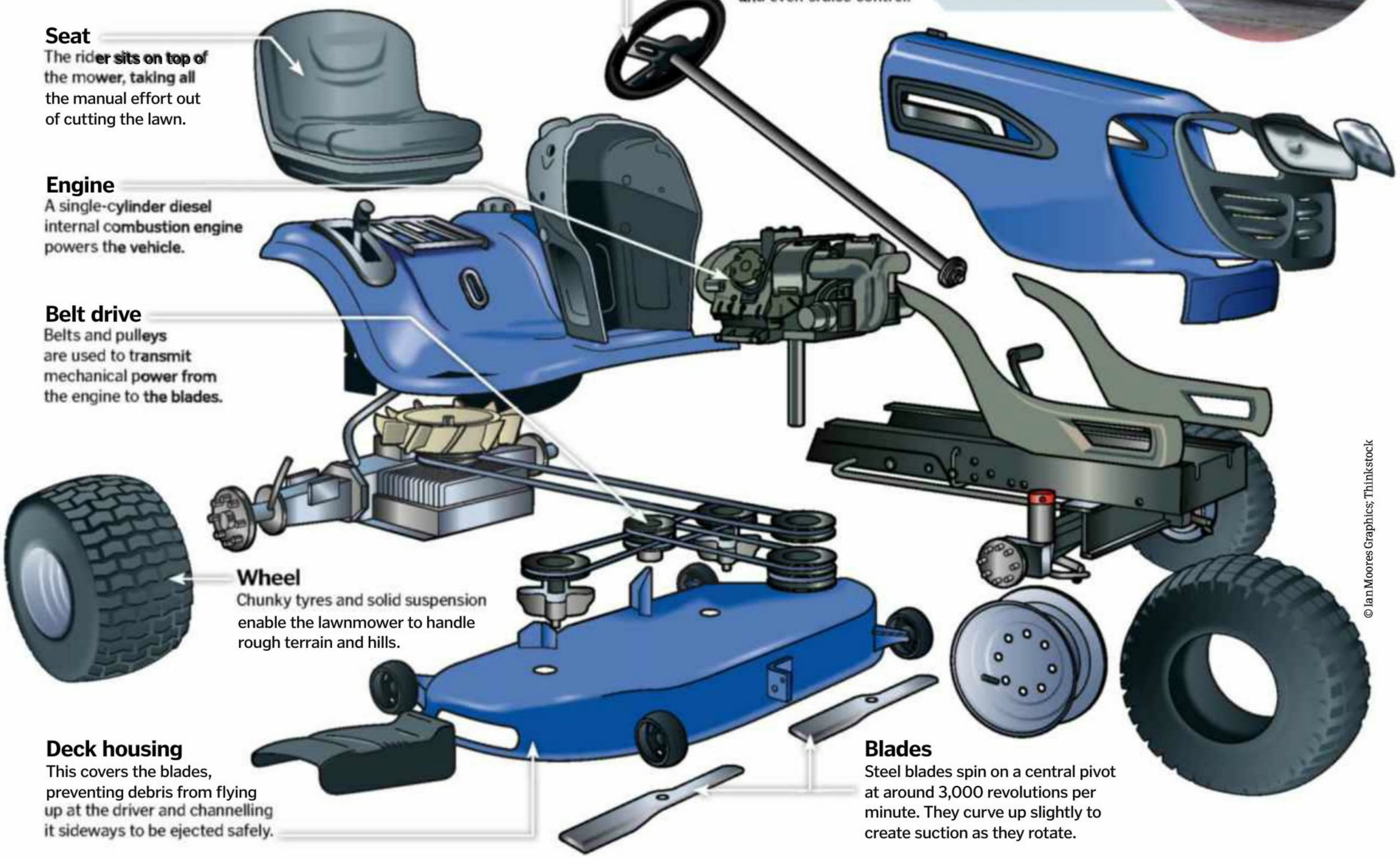
Rollers are sometimes added to mowers to smooth the grass after it has been cut and to cover up any wheel marks. These are also responsible for creating the characteristic stripy look often seen on football pitches and ornamental lawns.

Mowers on the move

Lawnmower racing in the UK started in 1973 as an easily accessible, sponsorship-free alternative motorsport. The lawnmower blades are removed for safety and racers compete in a variety of events, from relay races running behind normal push-along lawnmowers, to racing around dirt tracks at speeds of up to 80 kilometres (50 miles) per hour! There are even 12-hour endurance events raced in teams of three. Engine modification is not allowed, and there are no cash prizes, but riders can alter the belt pulleys to make the gearing faster and more efficient. It is officially the cheapest motorsport in the UK – and probably one of the strangest too!

Rotary mower engineering

Take a look inside an exploded sit-on mower



Seat
The rider sits on top of the mower, taking all the manual effort out of cutting the lawn.

Steering wheel
The controls are very similar to a tractor or car; more sophisticated models can have automatic gears and even cruise control.

Engine
A single-cylinder diesel internal combustion engine powers the vehicle.

Belt drive
Belts and pulleys are used to transmit mechanical power from the engine to the blades.

Wheel
Chunky tyres and solid suspension enable the lawnmower to handle rough terrain and hills.

Deck housing
This covers the blades, preventing debris from flying up at the driver and channelling it sideways to be ejected safely.

Blades
Steel blades spin on a central pivot at around 3,000 revolutions per minute. They curve up slightly to create suction as they rotate.

"Some are registered for road use, complemented with lower suspension and skinny tyres"

How do quad bikes work?

Small, lightweight and powerful, an all-terrain vehicle is the perfect companion for those who like to venture off the beaten track

A quad-bike, or ATV (all-terrain vehicle), is a four-wheeled sit-on vehicle used to travel efficiently over a variety of off-road landscapes. Its short wheelbase and four-wheel drive nature – paired with high ground clearance and large, grooved tyres – ensure a quad-bike is an able master of even the most bumpy surfaces and steep inclines.

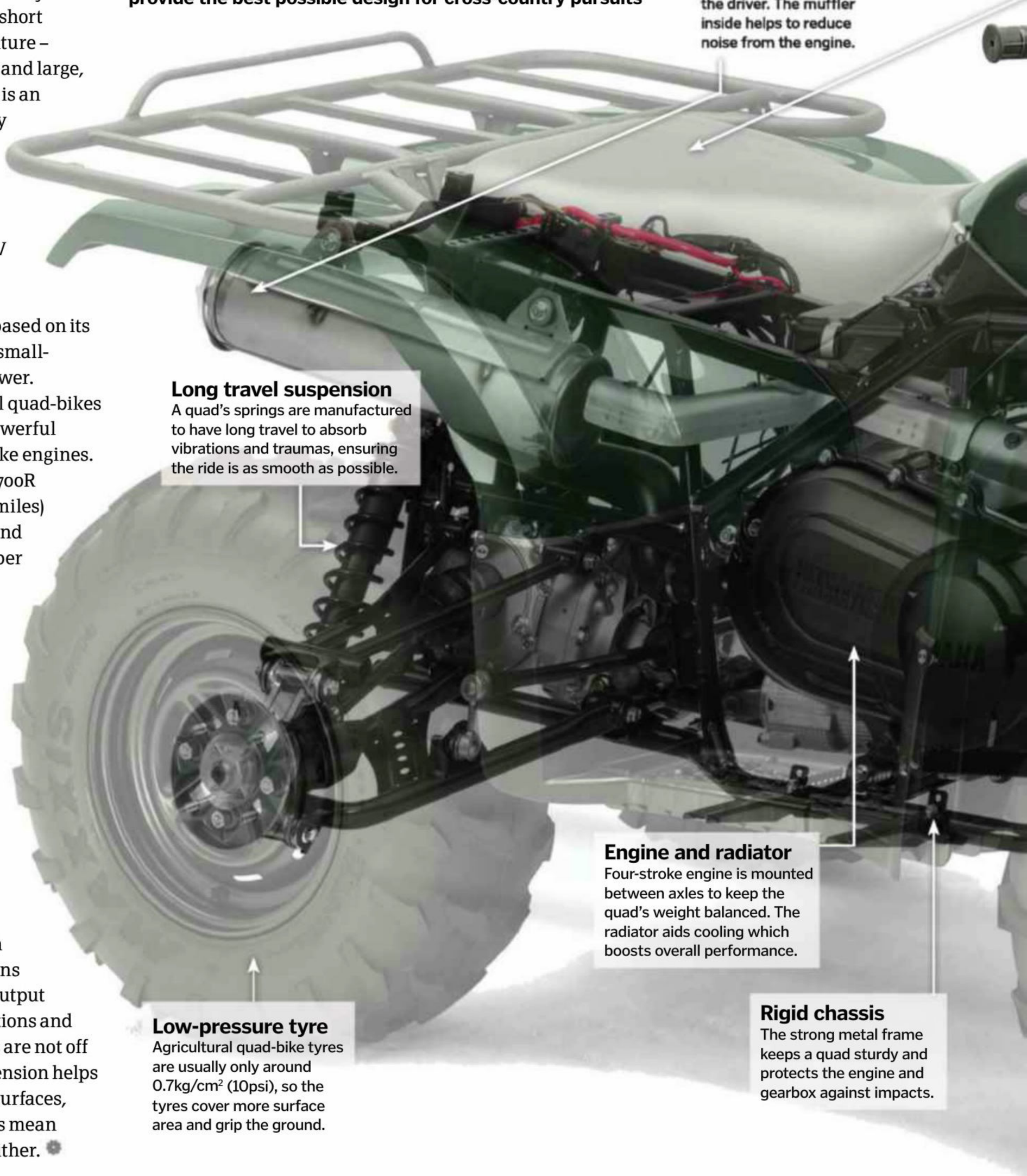
Quad-bikes were traditionally used by the agricultural fraternity, who favoured the versatility, pace and low fuel consumption of an ATV when transporting light goods or equipment around a farm. Honda developed the first modern quads based on its motorbikes in the Seventies, using small-capacity, two-stroke engines for power.

In the 40 years since, recreational quad-bikes have become considerably more powerful thanks to bigger-capacity, four-stroke engines. A top-of-the-range Yamaha Raptor 700R can accelerate to 48 kilometres (30 miles) per hour in just over two seconds, and will reach 80 kilometres (50 miles) per hour in a little over five. Quads can easily produce a respectable 50 Newton-metres (37 pound-feet) of torque and hit a top speed of 129 kilometres (80 miles) per hour, and as such some are now registered for road use, complemented with lower suspension and high-pressure, skinny tyres to better suit conditions on a public highway.

Technology on quad-bikes has also evolved considerably. Many now come with five-speed transmission (plus reverse) and can rev all the way up to 9,000 revolutions per minute for a prolonged power output up steep hills. With the right conditions and approach, even 60 per cent inclines are not off limits these days. Long travel suspension helps to counteract even the roughest of surfaces, while waterproof electrical systems mean most ATVs aren't afraid to get wet either.

Four-wheel fundamentals

Although basic in principle, advancements to modern ATVs provide the best possible design for cross-country pursuits



Exhaust and muffler
A stainless-steel exhaust carries fumes to the back of the vehicle and away from the driver. The muffler inside helps to reduce noise from the engine.

Long travel suspension
A quad's springs are manufactured to have long travel to absorb vibrations and traumas, ensuring the ride is as smooth as possible.

Engine and radiator
Four-stroke engine is mounted between axles to keep the quad's weight balanced. The radiator aids cooling which boosts overall performance.

Rigid chassis
The strong metal frame keeps a quad sturdy and protects the engine and gearbox against impacts.

Low-pressure tyre
Agricultural quad-bike tyres are usually only around 0.7kg/cm² (10psi), so the tyres cover more surface area and grip the ground.

1. LEAST POWERFUL

Royal Enfield

With a two-kilowatt (2.8-horsepower) engine Royal Enfield built the first quad-bike in the 1890s. It was originally designed for horseless carriage driving.

2. POWERFUL

Conquistador 6.6

This contemporary ATV made by LandFighter outputs 31 kilowatts (42 horsepower). High spring rates in the shock absorbers allow for improved handling on rough terrain.

3. MOST POWERFUL

Lazareth Wazuma V8

The most costly quad is £170,000 ($261,000). With its Ferrari V8 engine, it packs 186 kilowatts (250 horsepower).

DID YOU KNOW? *Between 1998 and 2002, hospitals witnessed a sharp rise in ATV-related injuries, going from 1,200 to 4,200*

Saddle seat

The saddle seat ensures the driver straddles either side of the quad-bike, spreading weight and enabling the driver to stand up and lean forward when climbing steep hills.

Handlebar

Motorbike-like handlebars enable steering with full grip from both hands at all times for optimum safety. Pull-brakes ensure quick and easy stopping.

Fuel tank

Fuel is stored above the engine to aid weight distribution, with the fuel cap at the top for easy top-ups.

Disc brake

High-performance ATVs use disc brakes similar to those found on cars for increased stopping power.

The dangers of quads

Quad-bikes may have revolutionised efficient, independent travel on multiple forms of terrain, but make no mistake: inexperienced hands, these machines can be very dangerous.

Despite its four-wheel nature, a high centre of gravity and powerful engine mean it's relatively easy to roll an ATV on uneven ground, just by making a sharp turn at pace. Injuries can easily occur, from being crushed underneath the vehicle to head injuries sustained on impact with the ground – especially if the driver isn't wearing a helmet.

To combat these pitfalls, a helmet is an obvious must and a legal requirement both on the road and in competitions. Some ATVs also come with an emergency kill switch cord that attaches to the driver and vehicle, turning off the engine when either end becomes separated, usually when a driver falls off. Power steering also helps to nullify driver fatigue in the arms – crucial when traversing demanding hills and tricky cambers.

ATVs in sport

ATVs now appear in a variety of sporting competitions such as trails, motocross, TT racing and speedway, bearing witness to some extensive modifications. Quad-bikes are significantly enhanced for each sport, tailored to suit the varying requirements. Most employ various weight-saving techniques, using smaller-capacity fuel tanks and lighter chassis components.

Competition ATVs are predominantly lower and wider than their more agricultural counterparts, with a lower centre of gravity aiding both traction and handling. Bigger-capacity engines are usually paired with revamped transmissions offering wide-ranging gear ratios, enabling power to be put down quickly. Speed-focused contests will also see ATVs competing with noticeably different tyres to recreational quad-bikes. Competition rubber has a much lower profile, a smoother tread pattern and is made from a harder compound, helping the quad to cover more ground quickly.

Many top-end ATVs today also come with selectable two or four-wheel drive and adjustable shock absorbers to best cope with the terrain associated with each sporting discipline.

The giant Brachiosaurus

Three times longer and two times taller than a double-decker bus, Brachiosaurus truly was a terrestrial titan of epic proportions

Brachiosaurus was a genus of sauropod dinosaur that roamed the Earth during the Late Jurassic period (circa 155-140 million years ago). They are characterised, like many sauropods of the time, by their huge necks and comparatively tiny skulls and brains. Currently only one species has been officially confirmed – B altithorax – though others have been suggested.

Interestingly, like other sauropods, these creatures – despite weighing an estimated 60 tons and measuring up to 30 metres (98 feet) long – were actually colossal vegetarians, with their diet comprising solely foliage.

Their evolution of such a long neck (see 'The high life' boxout for more details) seems to be intrinsically linked to their diet, with the elevated head position enabling them to access leaves unavailable to shorter species.

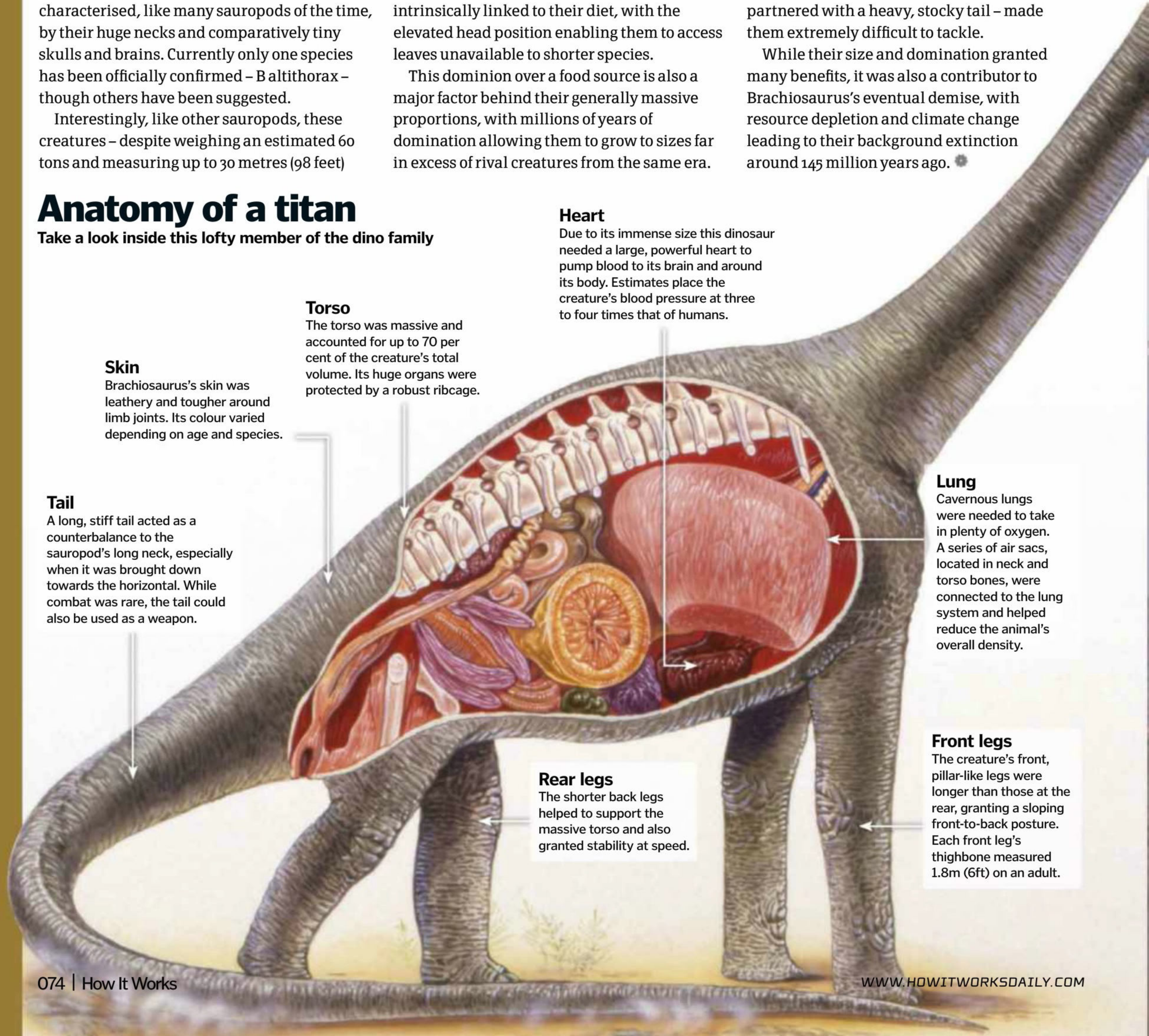
This dominion over a food source is also a major factor behind their generally massive proportions, with millions of years of domination allowing them to grow to sizes far in excess of rival creatures from the same era.

The epic size of Brachiosaurus was also its primary form of defence when it came to predators. Once fully grown, their legs would have resembled tree trunks and these – partnered with a heavy, stocky tail – made them extremely difficult to tackle.

While their size and domination granted many benefits, it was also a contributor to Brachiosaurus's eventual demise, with resource depletion and climate change leading to their background extinction around 145 million years ago.

Anatomy of a titan

Take a look inside this lofty member of the dino family



Heart
Due to its immense size this dinosaur needed a large, powerful heart to pump blood to its brain and around its body. Estimates place the creature's blood pressure at three to four times that of humans.

Torso
The torso was massive and accounted for up to 70 per cent of the creature's total volume. Its huge organs were protected by a robust ribcage.

Skin
Brachiosaurus's skin was leathery and tougher around limb joints. Its colour varied depending on age and species.

Tail
A long, stiff tail acted as a counterbalance to the sauropod's long neck, especially when it was brought down towards the horizontal. While combat was rare, the tail could also be used as a weapon.

Lung
Cavernous lungs were needed to take in plenty of oxygen. A series of air sacs, located in neck and torso bones, were connected to the lung system and helped reduce the animal's overall density.

Front legs
The creature's front, pillar-like legs were longer than those at the rear, granting a sloping front-to-back posture. Each front leg's thighbone measured 1.8m (6ft) on an adult.

Rear legs
The shorter back legs helped to support the massive torso and also granted stability at speed.

5 TOP FACTS
BRACHIOSAURUS

Habitat debate

1 During the 20th century many palaeontologists were convinced that, due to its long neck, Brachiosaurus spent much of its time submerged in water, but few believe this now.

Christening

2 Brachiosaurus's type species – B altithorax – was discovered in 1900 by American palaeontologist Elmer Samuel Riggs. It was first named in a paper written in 1903.

Secret hoard

3 Despite Riggs finding a bounty of specimens in 1900, none were put on display until 1994. Today the bones from his dig rest in the Field Museum of Natural History in Chicago, IL.

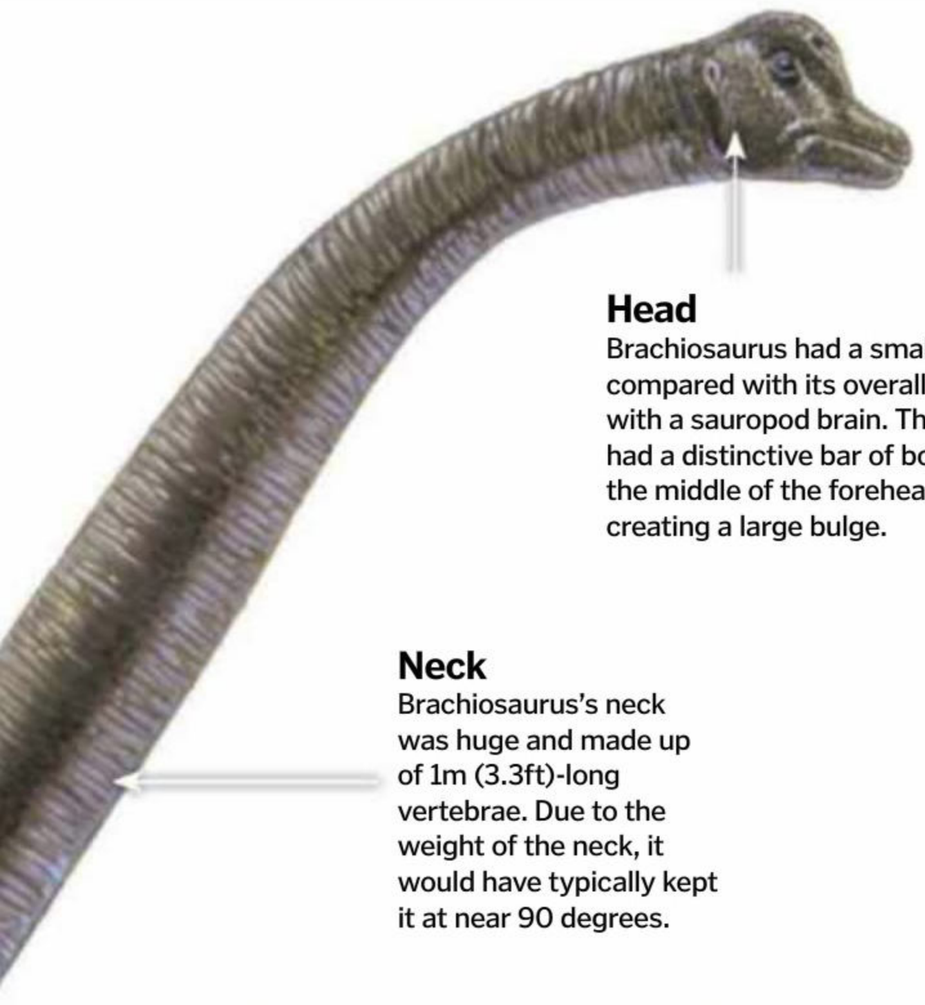
Dino in space

4 In 1991 an astronomer found an asteroid orbiting the Sun – something it does once every 4.6 years. This main belt asteroid has been officially named 9954 Brachiosaurus.

Movie star

5 The ronto creatures in *Star Wars* were based on the Brachiosaurus models used in *Jurassic Park*. Neither is very accurate compared to the historical creature though.

DID YOU KNOW? *Brachiosaurus could not rear up on its hind limbs as depicted in Jurassic Park*



Head

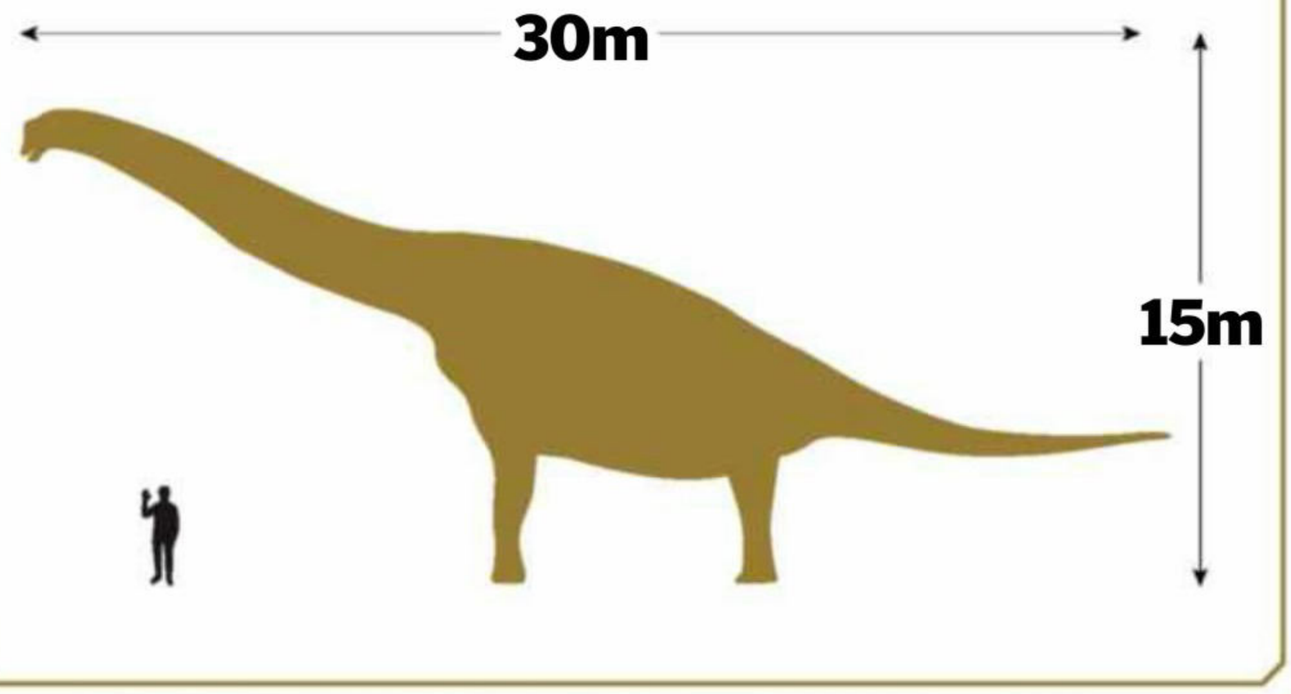
Brachiosaurus had a small head compared with its overall size, with a sauropod brain. The skull had a distinctive bar of bone in the middle of the forehead, creating a large bulge.

Neck

Brachiosaurus's neck was huge and made up of 1m (3.3ft)-long vertebrae. Due to the weight of the neck, it would have typically kept it at near 90 degrees.

Brachiosaurus vs human

How does this mega-dino size up to your average Homo sapien?



The statistics...

Brachiosaurus

Length: 25-30m (82-98ft)
Height: 15m (49ft)
Weight: 60 tons
Max speed: 29km/h (18mph)
Period active: 155-140 MYA
Life span: 100 years

The high life

Each vertebra in the neck of Brachiosaurus was approximately one metre (3.3 feet) in length, which is absolutely colossal compared with the largest animals around today. Combined, these vertebrae formed an extensive, snake-like neck that enabled the Brachiosaurus to reach up into tall trees and other plants with ease to feed on foliage – of which it needed vast quantities to survive.

Importantly, despite the long neck giving Brachiosaurus a keen browsing advantage when compared with other smaller dinosaurs, as a payoff it would have needed a near-vertical neck posture most of the time in order to prevent injury.

Unlike the popular 20th-century view that Brachiosaurus would raise and lower its head to access different tiers of foliage, it is now generally thought that only the immediate level around its head height would have been eaten, with lower tiers of leaves only consumed by juveniles.

Its name translates as 'arm lizard' because unusually for dinosaurs its front legs were longer than its hind legs

"As well as grinding grain, these mills could saw wood, make bobbins for textiles and produce gunpowder"

Water mill mechanics

How do these ancient systems harness the power of water and convert it to perform a variety of tasks?

Water mills were – and in rare circumstances still are – facilities in which moving water was used as the driving force to power a milling apparatus. The key component was a waterwheel, although in later times turbines were also employed, which converted the kinetic and potential energy of water into rotational mechanical energy to drive various machines. Most commonly the mill would grind grain to produce flour.

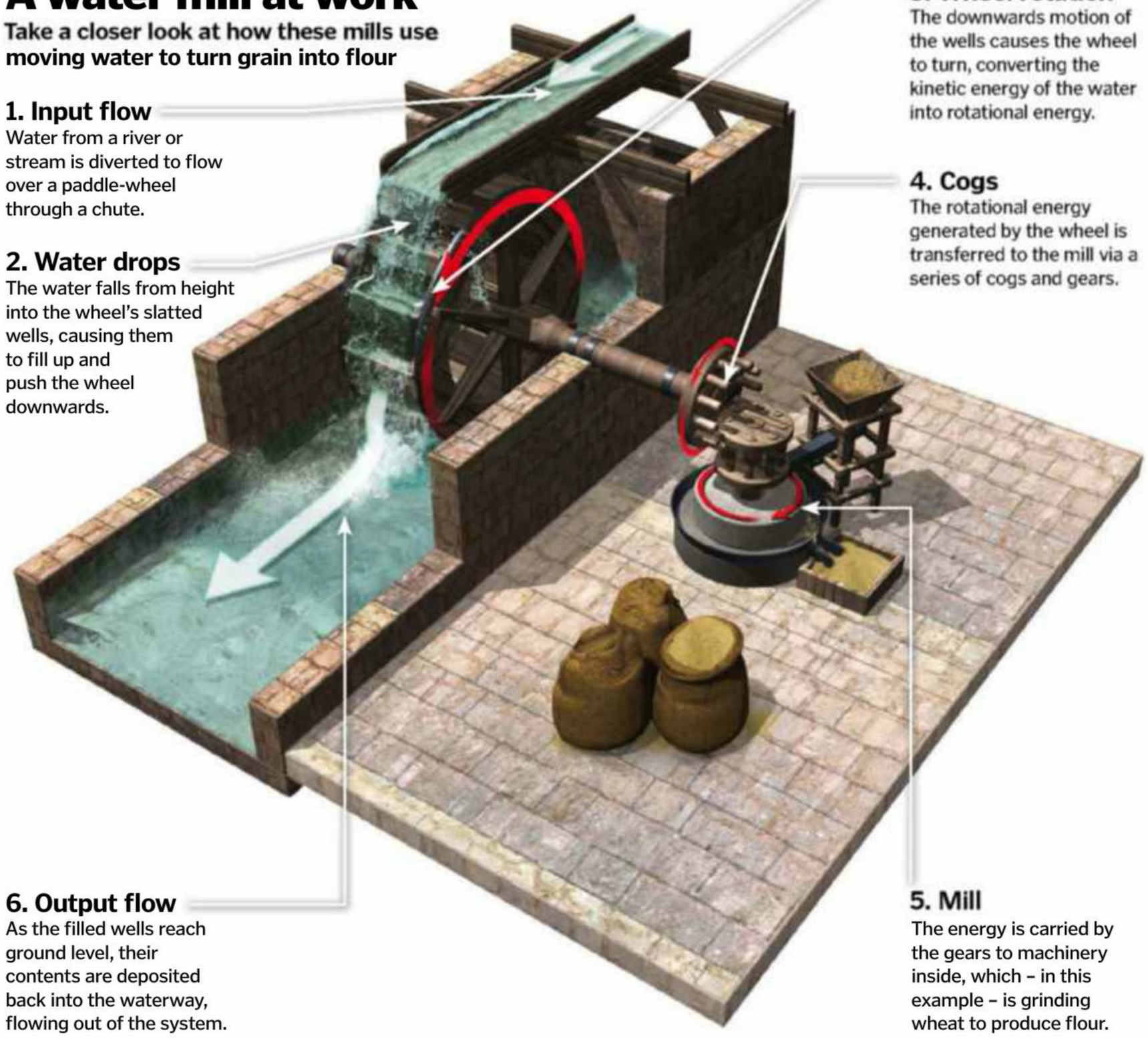
Historically there have been different types of water mill, each largely determined by the type of wheel they used. The kind of wheel chosen was dictated by the local geography and the source of water, with rivers on flat plains requiring an undershot waterwheel, while those dropping from elevated positions allowing for more efficient designs, like overshot wheels (see boxout for more information).

Water mills are thought to date back millennia and were used the world over right up to the early-20th century due to their versatility. As well as grinding grain, these mills could be used to saw wood, make bobbins for the textiles industry, produce gunpowder for armaments and crush ores for use in metalworking. Due to their popularity, designs evolved quickly, with each new type of wheel and gearing arrangement improving efficiency.

Today, water mills are used far less due to the availability of more efficient energy-production systems, however some still operate for demonstrative purposes.

A water mill at work

Take a closer look at how these mills use moving water to turn grain into flour



1. Input flow
Water from a river or stream is diverted to flow over a paddle-wheel through a chute.

2. Water drops
The water falls from height into the wheel's slatted wells, causing them to fill up and push the wheel downwards.

3. Wheel rotation
The downwards motion of the wells causes the wheel to turn, converting the kinetic energy of the water into rotational energy.

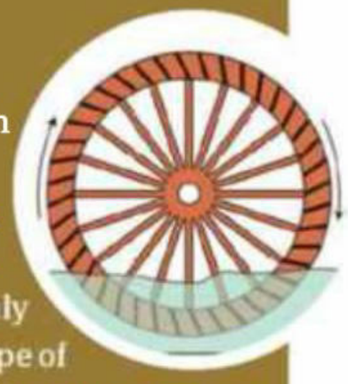
4. Cogs
The rotational energy generated by the wheel is transferred to the mill via a series of cogs and gears.

5. Mill
The energy is carried by the gears to machinery inside, which – in this example – is grinding wheat to produce flour.

6. Output flow
As the filled wells reach ground level, their contents are deposited back into the waterway, flowing out of the system.

Types of waterwheel

Undershot



If the mill is built on terrain with no slope available then the undershot wheel is the only option. This type of waterwheel is the oldest design and also the most inefficient, relying on large, fast-moving bodies of water to operate. Water pushes against the flat wooden slats of the wheel, making it rotate.

Overshot

If the water is dropping from a decent height (ie greater than 4.5 metres/15 feet), an overshot wheel can be used. These wheels are very efficient (around 80 per cent) as the water enters the wheel's slatted wells at the top and after a drop, maximising the power of both the liquid and gravity.

Breastshot

The breastshot is so named as its design permits water to approach the wheel halfway up its body. Once again, water drops into the slatted wells, causing the wheel to rotate under the weight, with the water flowing out of the wheel at its lowest point. This type works best with an approaching body of water that is two to three metres (six to nine feet) above ground level.

1. FAMOUS

Ajax
A mythological hero and key player in Homer's *Iliad*, Ajax is a warrior with the strength of many men. During the story he kills a lot of Trojan warriors.

2. MORE FAMOUS

Agamemnon
Also in the *Iliad*, but suspected by some to be real, Agamemnon was a warrior king of Mycenae. He was commander-in-chief of the Greek forces.

3. MOST FAMOUS

Heracles
A divine hero in Greek mythology, Heracles was the greatest warrior on Earth. The most gifted fighter in the Trojan War he slayed Prince Hector.

DID YOU KNOW? *Panoply is the term used to describe a complete set of hoplite armour and weaponry*

Greek warriors

The hoplites of Ancient Greece were some of the most feared fighters in the world – find out why they were so hard to defeat

Both in Homeric and post-Homeric Greece, hoplite warriors were considered the most deadly and efficient soldiers on the planet. Armed with a variety of highly refined weapons – such as spears, swords and daggers, protected by toughened bronze armour and adept at executing cunning tactics and formations, these Ancient Greek warriors tore through many an enemy army with considerable ease.

Arguably, hoplites really came into their own around the sixth century BCE. Prior to this point Greek warriors – who were self-armed and trained civilians – fought for personal, familial or national honour singularly. They obviously grouped under city-state banners to wage wars, but when the battle started, the onus was very much on man-to-man single combat; indeed, many battles of this period began with army commanders/heroes facing off against each other solo.

After the introduction of advanced military formations such as the phalanx – see 'Wall of death' boxout for more – circa 700 BCE, soldiers began to fight battles as cohesive military units.

This increased their battle prowess further and, by the time of the massive Persian invasion of 480 BCE, enabled them to win a series of decisive battles against forces that, going on the numbers, they should have lost.

Wall of death

Aside from their good training, weapons and armour, a key reason hoplite warriors were so feared was their use of formations. Chief among these was the phalanx, a rectangular mass formation composed of heavy infantry that, by engaging the enemy as one, allowed the warriors to effectively crush any foe in their path. The phalanx was created by arranging hoplites in lines typically eight to ten men deep, with the front rank of soldiers interlocking their shields together. The long rectangular body of soldiers would then slowly advance, spears outstretched, skewering any enemies ahead.

Hoplite kit

We look at the major armour and weapons used by these elite soldiers

Helmet
Various styles of helmet were worn, ranging from the heavy-duty Corinthian to the lighter Chalcidian variety seen here. The crest colour and design varied between city-states.

Breastplate
Both linen and metal breastplates were worn, with the richer and more important warriors wearing very ornate bronze examples. Here, the warrior is wearing a linothorax, a linen variety popular in later periods.

Sword
Hoplites also carried a short sword called a xiphos. This secondary weapon was only used when the spear was damaged or a phalanx formation broke ranks.

Spear
The primary weapon of any hoplite was a 2.5m (8ft)-long spear or lance. These were tipped with a leaf-shaped blade on one end and a short spike on the other.

Shield
The Ancient Greek warrior's shield was called an aspis and consisted of a concave circle of bronze-coated wood that measured 1m (3.3ft) across.

Greave
Metal greaves were common, with the pieces of armour hammered out of iron or bronze sheets. They stretched from the top of the foot to the knee.

"Whale oil was the backbone of many everyday products including soap, lamps and even foods"

Life on board a 19th-century whaling ship

How did these specialist vessels help a crew hunt down the highly prized marine mammals on perilous sea voyages that could last for months?

Whaling ships – otherwise known as whaleships during the 19th century – were sea vessels that were carefully designed for long-haul and dangerous operations. Manned by a skilled crew, their sole purpose was to hunt, capture and asset strip a variety of whales – notably baleens – across some of Earth's wildest oceans.

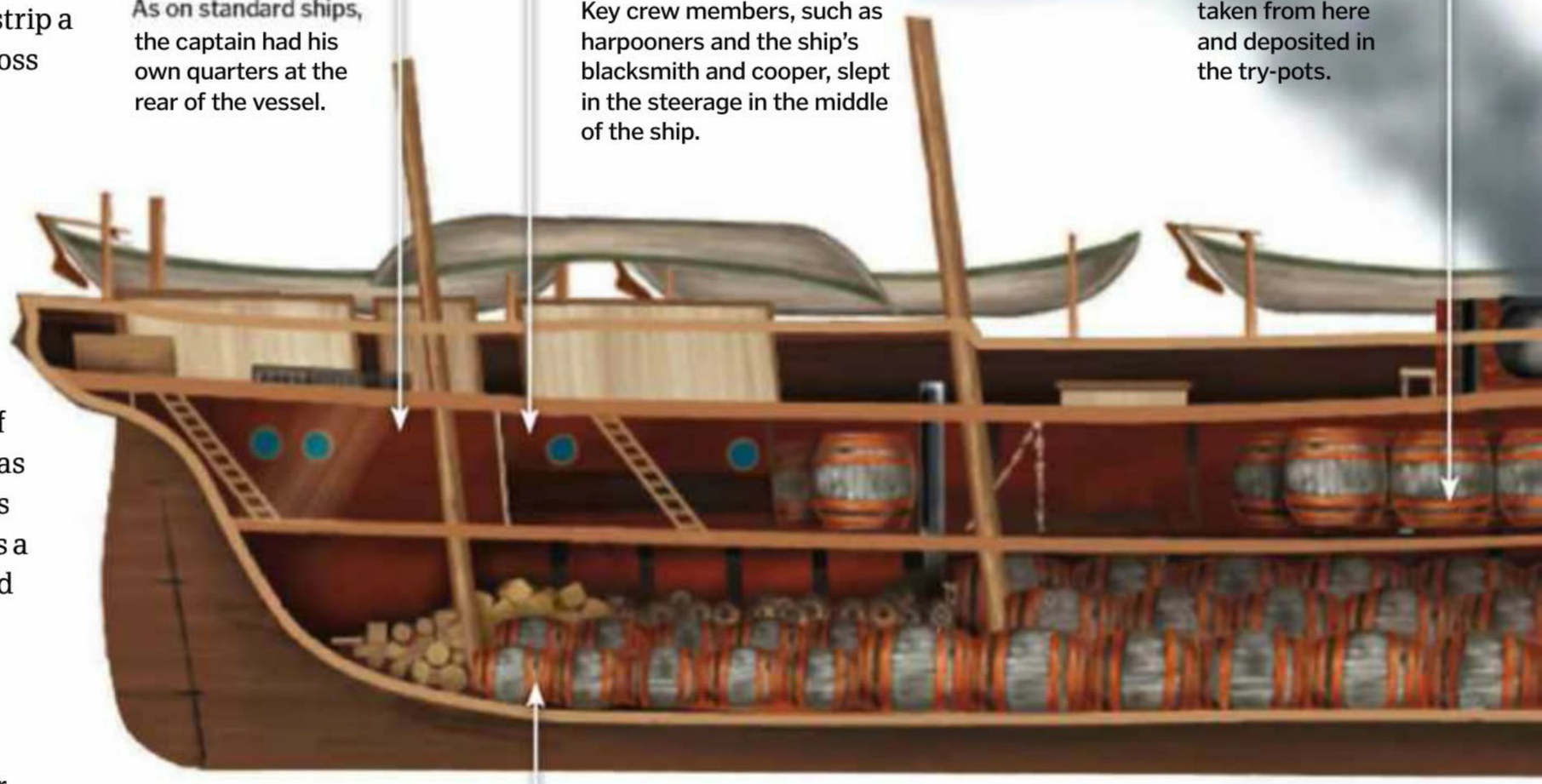
'Assets' consisted primarily of blubber – a layer of thick body fat found under the skin of all whales, which could be rendered down for its heavy oil content – though bones, meat and other parts were also salvaged. Oil, however, was the major goal for any whaleship, as prior to the introduction of kerosene and vegetable oils, whale oil was the backbone of many everyday products including soap, lamps and even foods. As a result, every whale that was caught could bring in a tidy profit back on land.

Oil was harvested from blubber on board the vessel in a 'try-works' – a processing system that consisted of two try-pots and a brick furnace. The blubber was boiled in the pots on the furnace, where its natural oils were siphoned off and stored in large casks below deck. The furnace itself was mounted on cast-iron struts to the deck, with a reservoir of underlying water to prevent the wooden planks from burning. Of course, to render the blubber first the crew needed to capture a whale.

The process of catching whales entailed hitting the creature with deck-mounted harpoon guns and then approaching on smaller whaleboats. Each whaleboat – which were carried like lifeboats on larger ships today – had its own crew and selection of arms, such as handheld harpoons, spears and guns. The carcass was then towed by the whaleboats back to the ship and 'flensed' – which involved the skin and blubber being cut off in strips before it was taken on board.

Whaler from deck to hold

Explore the main areas on a whaleship with our cutaway illustration



Captain's cabin
As on standard ships, the captain had his own quarters at the rear of the vessel.

Steerage
Key crew members, such as harpooners and the ship's blacksmith and cooper, slept in the steerage in the middle of the ship.

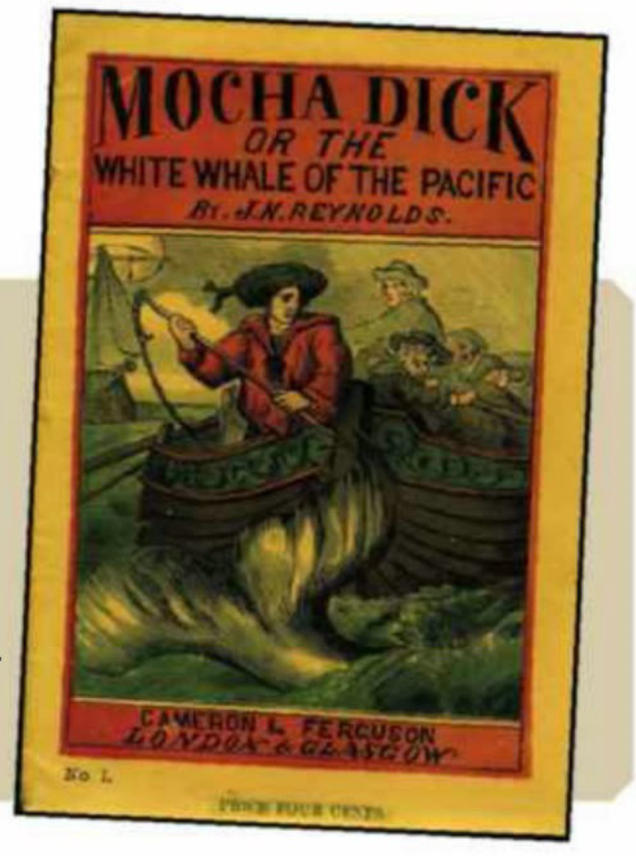
Blubber room
Stripped blubber was kept here in its own dedicated compartment. The strips were taken from here and deposited in the try-pots.

After hold
As much of the ship's storage was taken up with oil caskets, crew gear and provisions were stored in this area under the captain's cabin.

"Thar she blows!"

How accurate is the depiction of whaling in the classic American novel *Moby Dick*?

The writer of *Moby Dick*, Herman Melville, actually spent 18 months on a whaling ship – the Acushnet – from 1841 to 1842, where he got much first-hand experience of the trade. These experiences, along with the relayed tale of Mocha Dick – a notorious sperm whale that lived in the Pacific Ocean off the Chilean Mocha Island – became the basis for his famous novel. As such, the roles of crew members, speech used and activities portrayed are considered a relatively accurate representation of life on board a genuine whaler.

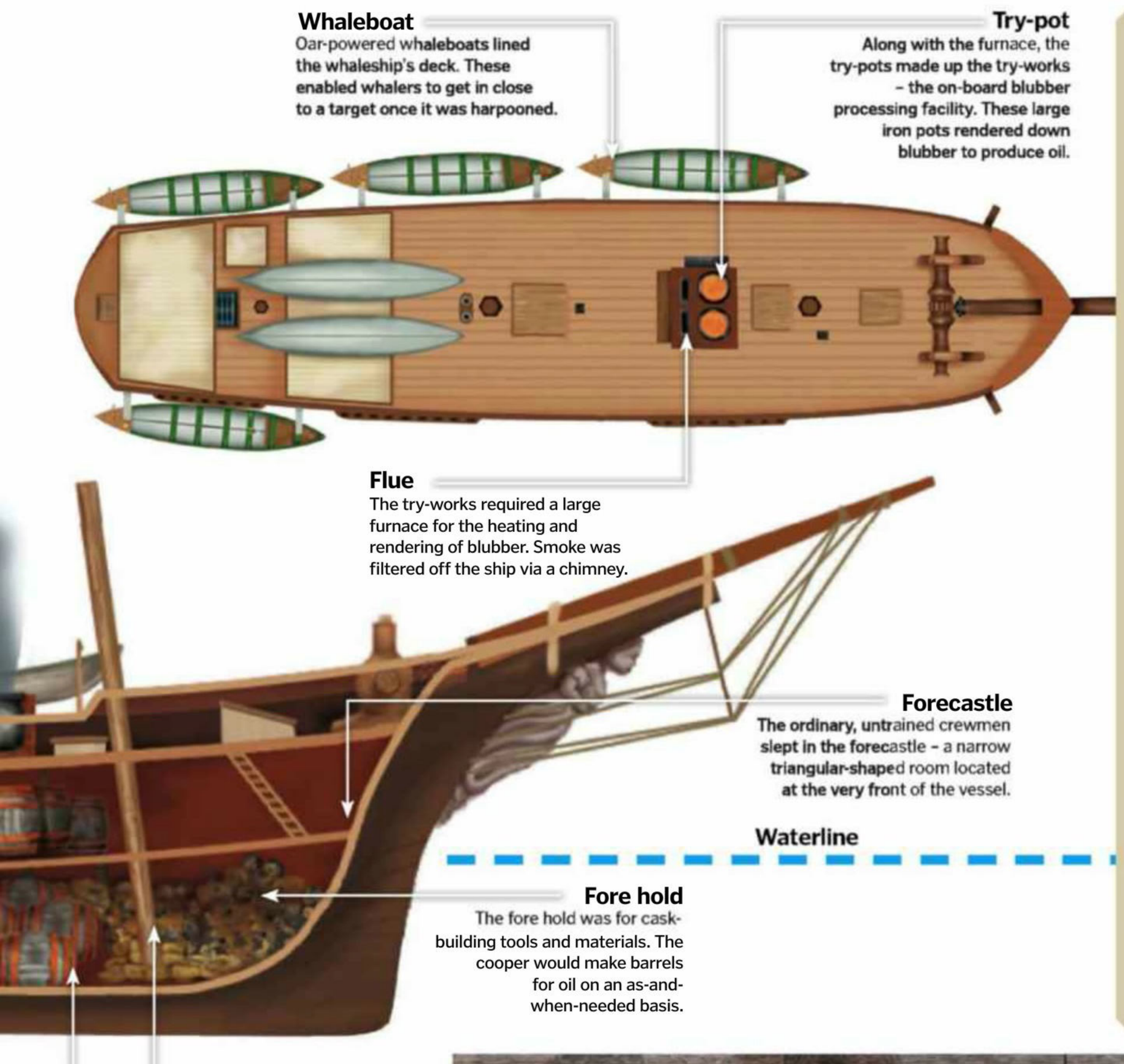


In *Moby Dick*, how many chapters feature the whale?

A 3 **B** 53 **C** 135

Answer:
Interestingly, despite the plot of *Moby Dick* principally revolving around an epic whaling expedition (illustrated left) to capture a bull sperm whale, the eponymous creature only appears in three of the novel's 135 chapters.

DID YOU KNOW? *Whaling voyages would frequently last for over a year at a time*



Fools' gold

How profitable was whaling for the average sailor?

The job of whaling was, even by sailing standards, very hard, with long journeys, harsh conditions and – in many cases – poor pay typically the norm.

No member of the crew received a weekly wage but instead got a journey-specific 'lay', which was a percentage of total profits. The size of the lay received depended on the status of the person on the vessel, with the captain receiving the lion's share and the lowliest crewman the least.

Obviously, each person's lay would depend on the number of whales captured, as the more oil that was brought back and sold, the more money would go into the communal pot.

Unfortunately though, often the lengthy whaling trips would bring in a limited oil haul, leaving the whaler in debt. In these cases it was common for the crew member to instantly sign up for another long-haul expedition as soon as they arrived back in port in the hope of paying off their arrears.

In this artwork, whaling ships in the South Sea are burning blubber after a successful day's hunting

© Getty

BRAIN DUMP

Because enquiring minds want to know...

MEET THE EXPERTS

Who's answering your questions this month?

Luis Villazon

Luis has a degree in Zoology from Oxford University and another in Real-time Computing. He's been writing about science and tech since before the web. His science-fiction novel *A Jar Of Wasps* is published by Anarchy Books.

Giles Sparrow

Giles studied Astronomy at UCL and Science Communication at Imperial College, before embarking on a career in publishing. His latest book, published by Quercus, is *The Universe: In 100 Key Discoveries*.

Alexandra Cheung

With degrees from the University of Nottingham and Imperial College, Alex has worked for several scientific organisations including London's Science Museum, CERN and the Institute of Physics. She lives in Ho Chi Minh City, Vietnam.

Rik Sargent

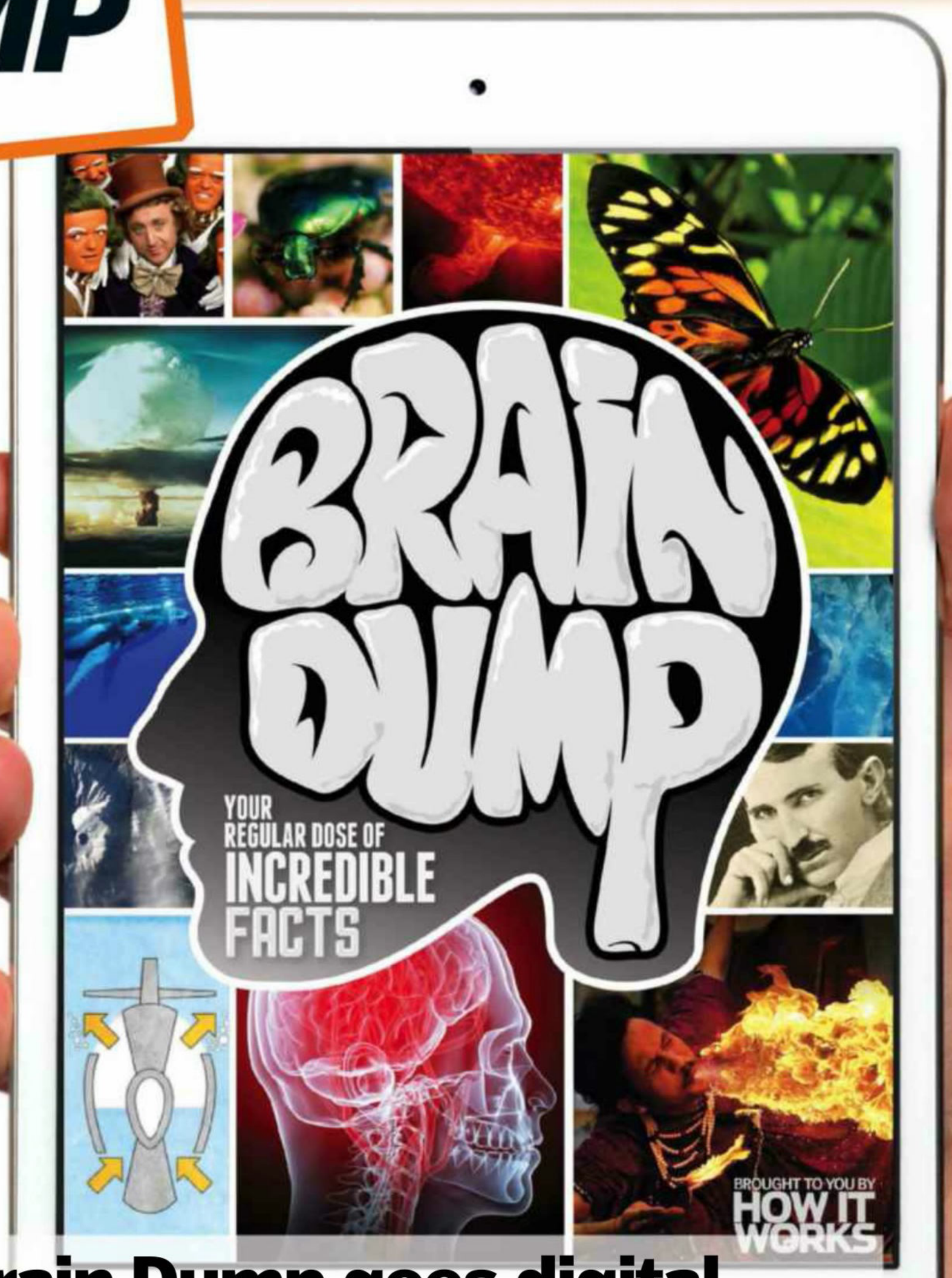
Rik is an outreach officer at the Institute of Physics in London, where he works on a variety of projects aimed at bringing physics into the public domain. By far his favourite part of the job is travelling to outdoor events and demonstrating 'physics busking'.

Dave Roos

A freelance writer based in the USA, Dave has researched and written about every conceivable topic, from the history of baseball to the expansion of the universe. Among his many qualities are an insatiable curiosity and a passion for science.

Ask your questions

Send us your queries using one of the methods opposite and we'll get them answered



Brain Dump goes digital

The new, instant and satisfying way to consume amazing facts on the go has finally arrived

has launched a brand-new digital Brain Dump app, essential for all you knowledge junkies out there. This digital-only magazine delivers your monthly dose of stunning images and factual content direct to your iPad or iPhone.

A one-of-a-kind app, Brain Dump dispenses 30 pages of clear and user-friendly information to keep fact-seekers entertained and enthralled while on the move. Every slide promises the captivating answer to one of life's essential questions, in the form of bite-sized nutritious knowledge.

With the digital Brain Dump in your pocket you'll have access to the ultimate fact fix wherever you are, and with subscriptions starting from $0.99/£0.69 this is essential reading for fact fans of all ages and abilities.

Search for Brain Dump (two words) on Apple Newsstand, or head to the official Facebook page at www.facebook.com/BraindumpMag and follow @BrainDumpMag on Twitter.

Where are the nearest star-forming sites to our Solar System?

Josh Ackroyd

The closest bright star-forming nebula to Earth is the much-studied Great Orion Nebula – located about 1,350 light years away – but there are plenty of other, fainter starbirth regions closer to our Solar System.

The closest known group of young stars is the TW Hydrae association, whose 30-plus members lie 175 light years away in the constellation of Hydra (the water snake). At roughly 5 million years old, several of these stars are still growing by pulling in gas and dust from their surroundings.

A number of full-blown starbirth nebulas lie around 500 light years away in southern hemisphere constellations, such as Chamaeleon and Corona Australis. They appear dark as they are only generating low-mass, Sun-like stars; they lack the high-mass giants whose brilliant radiation lights up brighter nebulas like Orion. **GS**

Although the Orion Nebula is only about 24 light years across, it is just one small part of a much larger star-forming region: the Orion Molecular Cloud Complex

Is it possible to change our fingerprints?

Shushanik Gyozalyan

Since fingerprints exist exclusively on the topmost layer of our skin, there are many ways in which they can be altered, although the effect is usually temporary.

Any repetitive abrasion to the skin can wear down the ridges, which is why veteran bricklayers can sometimes lose their fingerprints. Exposure to acids and bases, like agricultural lime, can also 'erase' fingerprints, at least until the epidermis grows back over 30 days.

In extreme cases, criminals have intentionally burned or otherwise scarred their hands in an attempt to disguise their fingerprints. However, the only permanent way to change your full set of fingerprints would be to undergo a double hand transplant, which although medically possible, does seem a little excessive. **DR**

Will holding your breath when someone sneezes stop you from catching their cold?

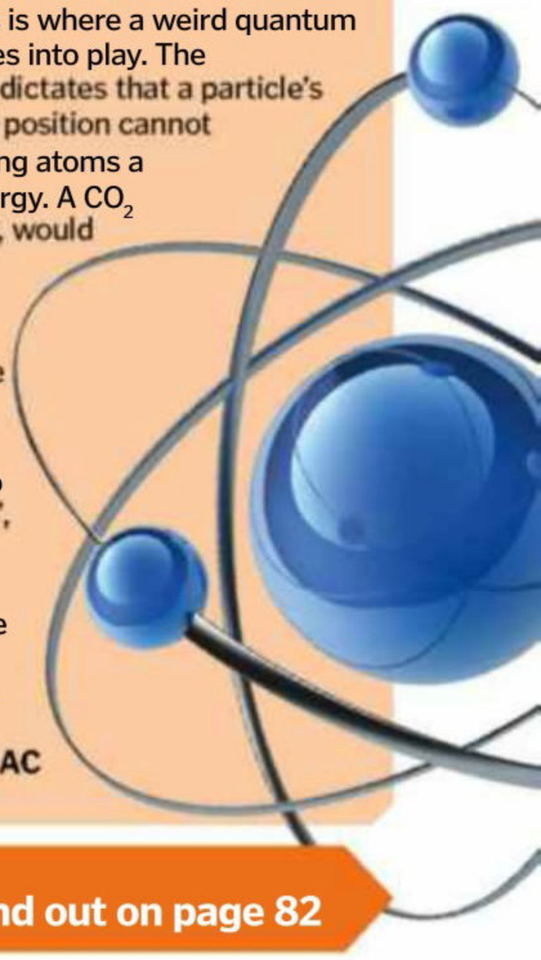
Bethany Williams

Holding your breath may help you to avoid a cold, but a far more effective method for staying virus-free is to wash your hands regularly and encourage any sick people around you to do the same. When someone has a cold, the cold virus multiplies inside their nose and throat secretions. Each cough or sneeze then expels tiny droplets containing the virus. Breathing in these droplets can lead to infection, but the most common way of catching a cold is actually by touch. After sneezing into their hands, the sufferer touches other people, objects or surfaces such as towels or door handles. This can in turn contaminate other people's hands, enabling the virus to enter their bodies when they touch their face or when they eat. **AC**

Is the slowest thing in the world an atom at near absolute zero?

Ingrid Wall

As temperatures decrease, atoms and molecules lose kinetic energy, implying that they should grind to a halt when they approach absolute zero. But this is where a weird quantum mechanics quirk comes into play. The 'uncertainty principle' dictates that a particle's exact momentum and position cannot both be known, allowing atoms a minute amount of energy. A CO_2 molecule, for example, would still rotate at a speed equivalent to several tens of centimetres per second at absolute zero. In any case, the uncertainty principle makes it impossible to measure such 'motion', or 'rotation'. The slowest speeds on Earth might instead be those of our planet's tectonic plates, which shift by just a few centimetres per year. **AC**



If a hippo and rhino had a fight, which would win? Find out on page 82

BRAIN DUMP

Because enquiring minds want to know...

Can we look at the big bang?

Find out on page 83

Want answers?

Send us your questions using one of the methods opposite and we'll get them answered

Has any satellite orbiting Earth ever been hit by space junk or meteoroids?

Jamie

The most notable collision involving a satellite was in 1993, when the large communications satellite Olympus-1 became caught up in a severe meteor shower. Spinning out of control, the satellite used up all its fuel in an effort to readjust its trajectory and was rendered useless. Collisions are rare and many satellites now have tracking systems in place to shift their course when potential collisions are imminent. The biggest danger for satellites, however, is not from large asteroids, but from the millions of tiny leftover pieces of defunct satellites. At less than one centimetre (0.4 inches) in diameter they are far too small for us to track, and can travel at speeds of 35,400 kilometres (22,000 miles) per hour – so fast that even a fleck of paint could cause devastation to a satellite. **RS**

Why do batteries seem to experience a reduction in overall charge over time?

Robert Philipson

The longer you own a portable gadget – whether it's a laptop, a smartphone or an MP3 player – the shorter its battery life becomes. One reason for this is the chemical reaction that powers rechargeable lithium-ion batteries.

Every time that you charge the cell, an electrical current pushes lithium ions from the battery's cathode (made of lithium cobalt oxide) to a graphite anode. When you turn on your device, the lithium ions flow in the opposite direction. With each charge/recharge cycle, the cathode material 'degrades' slightly, meaning its internal crystalline structure is altered so that some of the lithium ions refuse to make the trip to the anode. As more lithium ions get tied down, the battery loses capacity. High temperatures also speed up a chemical reaction that degrades the graphite anode. As a precaution, try not to use or store your device in temperatures above 35 degrees Celsius (95 degrees Fahrenheit). **DR**

Who would win in a fight between a hippo and a rhino?

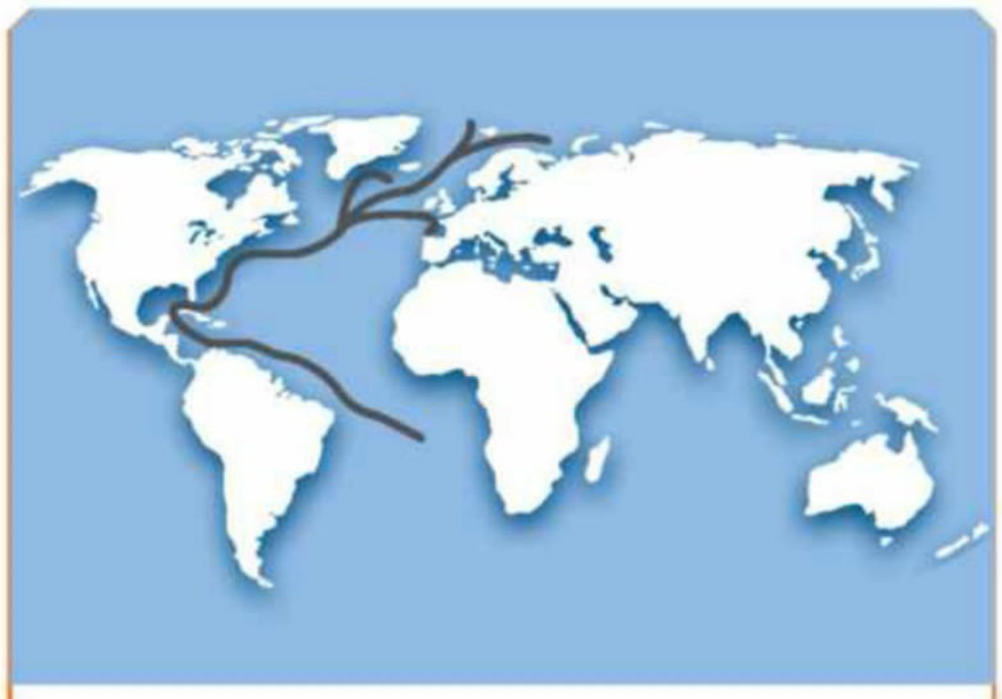
Jake Hanett

It would be a fairly close thing, which is probably why they almost never clash head to head in the wild. Both animals are highly territorial, but the hippo is much more aggressive. Fights between two male rhinos normally don't amount to more than some horn clashing and a little urine spraying. Male hippos, on the other hand, regularly inflict serious injuries on each other with their massive teeth. The rhino has an impressive charge, but in close combat the enormous gape of the hippopotamus's mouth probably gives it the advantage over the long, unwieldy horn of the rhino. **LV**

Could we build a Doctor Who-like TARDIS?

Susie Porter

There are certain, highly speculative branches of physics that hint at ways to make an object bigger on the inside than it appears on the outside. For example, the entrance to the TARDIS could be an Einstein-Rosen bridge, ie a wormhole. This would allow the inside of the TARDIS to be located on another planet far away, and when the TARDIS travels all that moves is one end of the wormhole. Alternatively, the inside of the TARDIS could extend into the fourth dimension, like cutting a hole in a piece of paper. Unfortunately, we don't know of any way to cut a hole in our 3D space and wormholes theoretically require exotic matter with negative mass to stabilise them, which so far no one has discovered. Current mathematical models of the universe don't prohibit such things existing, but that's not the same as saying they are possible, or that we could safely travel through them. **LV**



What is the Gulf Stream?

Bill Sexton

The Gulf Stream is a warm ocean current about 100 kilometres (62 miles) wide and 800 metres (2,625 feet) deep that runs from the Gulf of Mexico, up the coast of North America and across the Atlantic to the UK and eastern Europe.

It actually starts in west Africa as the Atlantic North Equatorial Current. In both directions, its power comes from the wind. Because the Earth is rotating, air currents tend to form large eddies, a little like the foam when you stir a cappuccino. North of the equator these cells rotate clockwise, which means the wind blows west in the tropics and eastwards at mid-latitudes. As warm surface water from the Caribbean is cooled by the wind it also becomes saltier via evaporation, which makes it denser, so in the northern Atlantic the Gulf Stream sinks to become a southward deep-water current. **LV**

Is peppermint tea good after surgery?

Joan Fulton

Peppermint tea is sometimes recommended after surgery due to its effects on digestion. Peppermint relaxes the muscles along the intestinal tract and can help patients to pass excess gas which may follow an operation. Some studies have also shown that peppermint oil may ease the nausea brought on by anaesthesia. More generally, peppermint oil can relieve a number of digestive ailments including indigestion or irritable bowel syndrome (IBS). The menthol inside peppermint is also a decongestant and can thin mucus to relieve blocked noses or coughs when we have a cold or flu. **AC**

How are odds affected by a die's number of faces?

Henry (age 11)

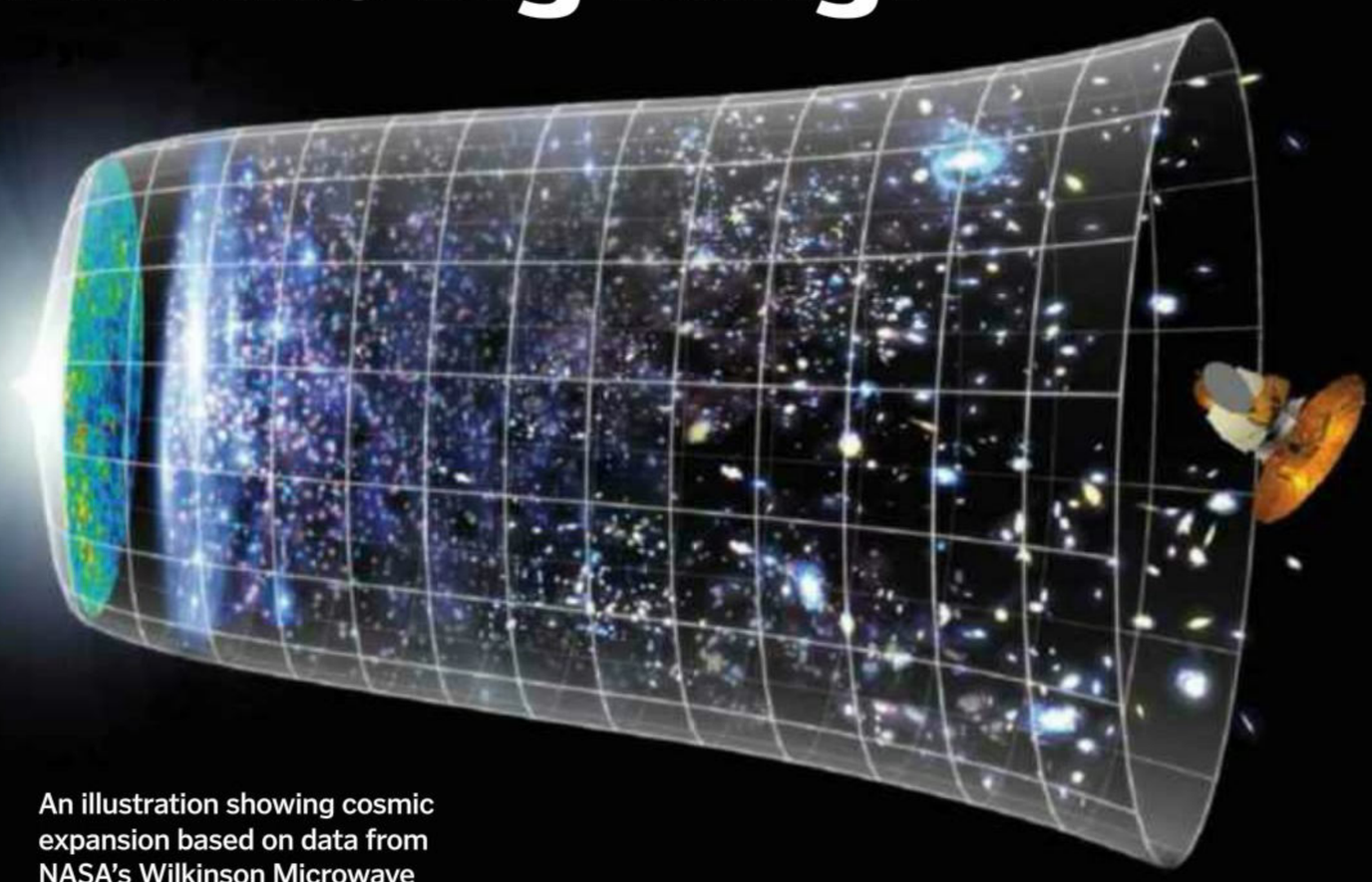
If you toss a coin, both sides have an equal chance of landing face up. There are only two possible outcomes: heads or tails. Rolling a cubed die gives six possible outcomes: six faces each as likely to land face up. 12-sided dice have 12 possible outcomes, and therefore twice the uncertainty that a given number will be rolled than with a standard die. The more sides, the greater the uncertainty in trying to correctly predict a rolled number. A die must have faces of the same shape and size, with angles that exhibit symmetry, for an equal chance that each will land face up. Shapes following this rule are called isohedra, and the most common isohedra for dice are the five platonic solids; the tetrahedron (four faces), cube (six), octahedron (eight), dodecahedron (12) and the icosahedron (20). **RS**

In which direction do we look to see almost as far back as the Big Bang?

Paul Caughers

One of the strange things about our expanding universe is that we can actually look in any direction and see light from the Big Bang. If you think of the Big Bang as happening at a single point in space, this is pretty confusing, but it makes more sense if you understand that the Big Bang happened everywhere in space at the same time, and it's space itself that has expanded ever since.

The light we can detect from the Big Bang emerged out of an expanding 'foggy' fireball when the universe became transparent about 13.8 billion years ago, just 380,000 years after the explosion itself. Thanks to its long journey across the ever-growing cosmos, it's now been stretched so that we detect it not as visible light, but as microwave radio waves. We can only see this 'background radiation' from parts of the universe that are at just the right distance for the radiation to be reaching us right now – so that's why it seems to come from 13.8 billion light years away, regardless of the direction we look in. **GS**



An illustration showing cosmic expansion based on data from NASA's Wilkinson Microwave Anisotropy Probe (WMAP)

How does the Sun keep burning without oxygen? Find out on page 84

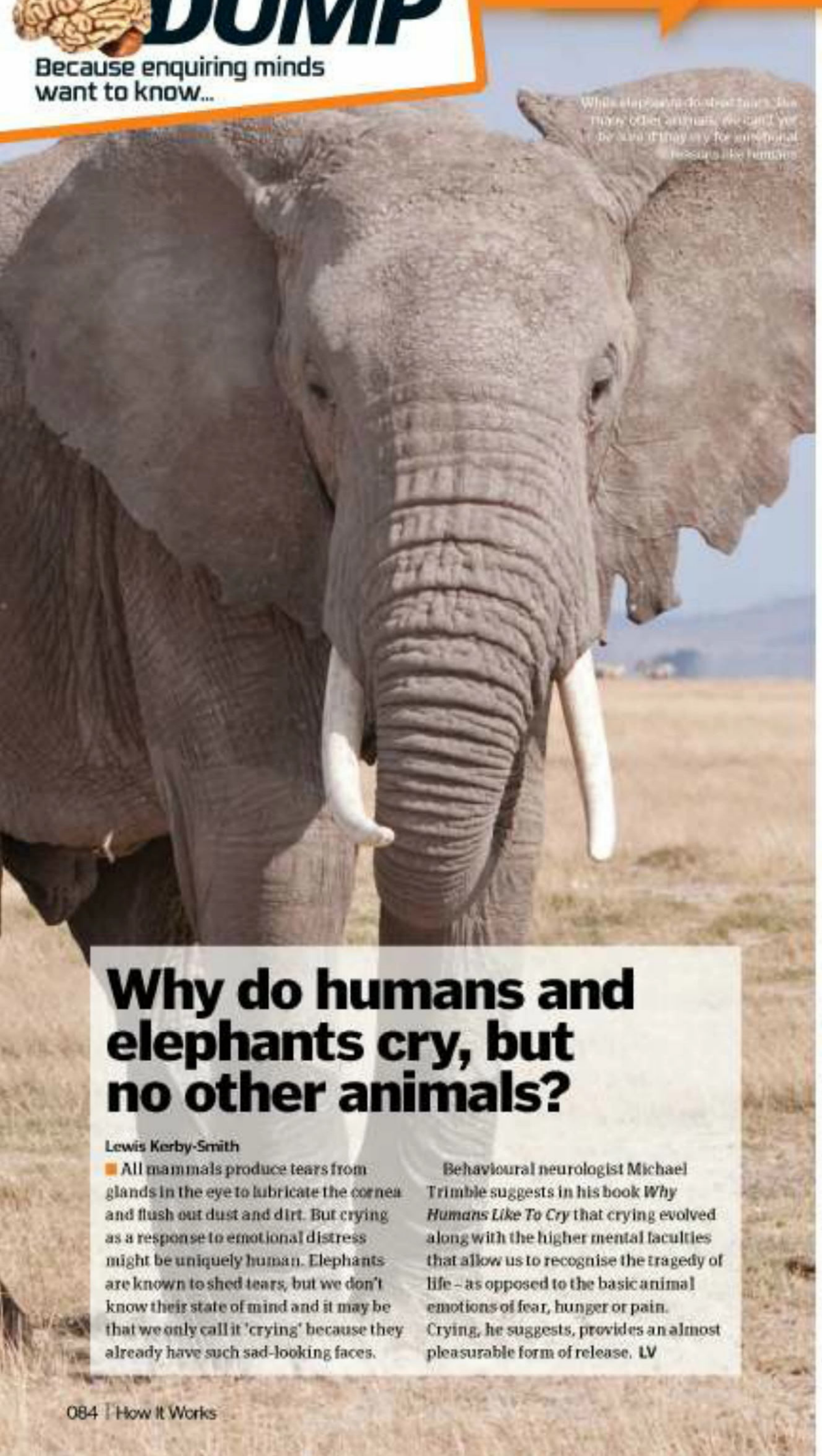
BRAIN DUMP

Because enquiring minds want to know...

How do ale and lager differ?
Find out on page 85

Want answers?

Send us your questions using one of the methods opposite and we'll get them answered



Why do humans and elephants cry, but no other animals?

Lewis Kerby-Smith

All mammals produce tears from glands in the eye to lubricate the cornea and flush out dust and dirt. But crying as a response to emotional distress might be uniquely human. Elephants are known to shed tears, but we don't know their state of mind and it may be that we only call it 'crying' because they already have such sad-looking faces.

Behavioural neurologist Michael Trimble suggests in his book *Why Humans Like To Cry* that crying evolved along with the higher mental faculties that allow us to recognise the tragedy of life – as opposed to the basic animal emotions of fear, hunger or pain. Crying, he suggests, provides an almost pleasurable form of release. **LV**

Is it true that people were executed as witches during medieval times?

Jessica Wells

Tens of thousands of people accused of witchcraft were burned or hung across Europe, the UK and the American colonies, but the height of the witch panic occurred well after the medieval period. In fact, the worst frenzy of witch-hunting, known as the Burning Times, occurred between 1580 and 1662. An estimated 50,000 people were put to death for witchcraft during this period, mostly in Germanic regions of Europe, although about 500 were executed in England. Witches were accused of conspiring with the devil to conjure spells that caused all manner of misfortune: illness and death, crop failure, storms and floods, etc. Historians now believe that score settling and scapegoating played large roles in the trials and executions of suspected witches, a quarter of which were men. In the famous case of the Pendle witches, most of the condemned came from two feuding families that accused each other of committing various atrocities. The Witchcraft Acts, which made sorcery punishable by death, were repealed in England and Scotland by 1736. **DR**

How does the Sun burn if there is no oxygen in space?

Christopher Attwood

At first glance, the Sun's surface might resemble the flames of a roaring fire, but that's deceptive – our local star isn't really burning in the same way things do on Earth. Confusingly, when astronomers talk about the Sun 'burning', they're actually talking about a completely different process called nuclear fusion. This involves forcing together the tiny nuclei of hydrogen (the lightest element) to create atoms of helium (the next lightest) in the high temperatures and pressures of the core. The process releases energy in a much more efficient way than the combustion we're familiar with in a fire – and it doesn't need oxygen. **GS**

Are there any technical differences between lager, ale and beer?

Brad Stenson

It's a common debate and there are indeed some basic distinctions. Beer is any alcoholic beverage primarily made from grain, hops, water and yeast. Grain is heated in water to release sugar then hops are added to lend a complex flavour and bitterness to contrast with the sugar. Yeast is then introduced to ferment the sugar, producing alcohol and CO_2. Lager and ale are both types of beer, but they undergo differing fermentation.

Ale is fermented using yeast that rises and works best at warmer temperatures (15-24 degrees Celsius/59-75 degrees Fahrenheit). Lager uses yeast that sinks and prefers cooler temperatures (5-12 degrees Celsius/41-53 degrees Fahrenheit). As a result, lager takes longer to ferment than ale, plus the colder fermentation inhibits the production of esters – the compounds responsible for fruity aromas and flavours often found in ale. **RS**

Could we build a plane with a glass bottom?

Elliot Williams

Unfortunately, see-through planes are not yet possible. For a 2013 April Fool's joke, Virgin Atlantic announced the launch of a new glass-bottomed airliner. China's state news service CCTV missed the joke and reported it as the latest eccentric whim of CEO Richard Branson. The problem is, in a commercial airline, the area beneath the cabin is occupied by luggage, landing gear and critical structural supports, none of which can be sacrificed for an unimpeded view of the scenery below. Besides, unlike a glass-bottomed boat, the view from the sides of a plane is pretty much the same as what you'd see through the floor. **DR**

Neanderthals were recently found to have eaten vegetables as well as meat, though this wasn't enough to stop them going extinct

How did our sense of taste help us evolve?

James Dahlgreen

The sense of taste is our body's gatekeeper, promoting our species' survival by encouraging us to eat things that we need and avoid those that could harm us. Like many other animals, our early ancestors evolved an aversion to bitter flavours, helping to evade plant toxins. In an environment where food was often scarce, they grew to love salty, umami (a savoury, meaty flavour) and sweet foods, driving them to fill up on nutritious, energy-rich snacks.

Experience also shapes human food preferences, allowing us to acquire certain tastes (eg coffee), or conversely develop an aversion to foods which have made us sick in the past. In developed countries today, the widespread availability of food and our fondness for calorie-laden and salty foods have contributed to obesity, diabetes and heart problems. So the same tastes which helped early humans are perhaps no longer such an advantage... **AC**

If two people poured water into a hole through the Earth, what would happen when it met?

Toby Stanford

In theory, if you poured water down this sort of well from both ends, it would experience less and less gravity as it fell: the mass of Earth's rocks pulling it from below would diminish, and be counterbalanced by the increasing mass of rock behind it. At the exact centre, the pull of gravity from all sides is balanced out, creating a situation of effective weightlessness, but the diminishing downward force lasts all the way to the centre. Normally a falling object dropped down the well would 'yo-yo' from one side of Earth to the other before eventually settling in the middle.

But if two streams of water hit each other in the centre, they'd stop each other dead and coalesce into a single floating mass – a bit like the way water behaves on spacecraft. That's if you could somehow stop it from evaporating in the tremendous heat, of course! **GS**

THE KNOWLEDGE

FOR CONNOISSEURS OF KIT AND SAVANTS OF STUFF

21st-century turntable

Pro-Ject Debut Carbon

Price: £300/$399
Get it from: www.henleydesigns.co.uk

Despite the music industry increasingly turning digital, with a wide selection of albums available in digital file formats, physical media – and specifically LP records – remains the go-to choice for the majority of audiophiles.

This trend is no more evident than in the continuing success of the Pro-Ject Debut series of turntables. Originally introduced in the late-Nineties, it is still delivering high-quality music playback over a decade later.

Interestingly, the renaissance of LP now seems to be filtering down from the enthusiast to the mass market, with Pro-Ject's latest offering – the Debut Carbon – bringing a bucketload of advanced playback tech to users at a pocket-friendly price point.

For a very reasonable £300 ($399) the Debut Carbon boasts a belt-driven 300-millimetre (11.8-inch) metal platter coated with felt mat, 33 and 45 rotation-per-minute speed modes, a stainless-steel main bearing and, most impressively, a 218-millimetre (8.6-inch) carbon-fibre tonearm. This latter element in particular is most welcome, with the arm reducing resonance and thus contributing greatly to the device's vivid sound quality.

Maybe the Carbon's most appreciated feature though is its super-easy setup. The excellent Ortofon cartridge comes already installed along with the deck's junction box, meaning that aside from a couple of weights and a bit of component tweaking, the deck is ready to go out of the box. This seems in keeping with the turntable's entry-level aspirations.

Combined, the solid components, ease of setup and delightfully modern, minimalist finish – available in several colours – make the Debut Carbon the ideal turntable for budget-minded audiophiles and amateurs alike.

Verdict:

The statistics...

Speed:
33/45 rpm (manual speed change)

Platter diameter:
300mm (11.8in)

Tonearm length:
218mm (8.6in)

Dimensions:
415x118x320mm (16.3x4.6x12.6in)

Weight:
5.6kg (12.3lb)

Overhang:
18.5mm (0.7in)

Wow and flutter:
+/- 0.10%

Speed drift:
+/- 0.80%

Tracking force:
10-30mN

Drive
The turntable operates off a belt drive and is capable of 33 and 45 rpm, albeit with a manual speed change.

Platter
The Carbon's 300mm (12in) platter is metal with a felt mat.

Finish
The Carbon comes in seven gloss finishes, ranging from classic silver or black to bright green.

Cartridge
The top-quality Ortofon cartridge comes pre-installed, making for a quick setup.

Tonearm
The turntable comes with a one-piece carbon-fibre tonearm which really enhances audio output.

BITE-SIZE REVIEWS

Your essential guide to the other awesome stuff we like this month

Breffo Adventure Camera Kit

Price: £20/$30
Get it from: www.breffo.com
Coming in both black and white, the Adventure Camera Kit is a neat and flexible way to attach digital cameras and camcorders to a variety of surfaces and objects. It consists of an eight-legged, soft rubber-coated, arachnid-like assembly (called a Spiderpodium) with screw fitting and each leg is capable of independent bending and twisting. This ability enables you to wrap the legs around most things – like a bike's handlebars – and then have your journey recorded by the camera. It's a simple thing, yet after testing, it was surprisingly effective and generated some exciting, on-the-go footage.

Verdict: ●●●●○

Cocktail Audio X10 (500GB)

Price: £316.63/$N/A
Get it from: www.sygnifi.co.uk
Supporting a vast range of file formats – including the handy FLAC and WAV varieties – the Cocktail Audio X10 hi-fi/media streamer is a really tidy piece of kit. It is capable of ripping and then storing up to 7,500 CDs' worth of content to its 500GB internal hard drive (although 1TB/2TB versions are available for more cash). You can then stream and copy those files across a home network for dynamic playback. Essentially the X10 acts as a compact hub in which a user's entire audio collection can be stored. With a clear interface and variety of inputs, as well as the ability to listen to internet radio, it's hard to argue with the price.

Verdict: ●●●●○

GROUP TEST

PUTTING PRODUCTS THROUGH THEIR PACES

Remote-control vehicles

How It Works takes some hot new electric RC cars out for a spin...

PROS
- Great, futuristic styling

CONS
- More fragile than competition

PROS
- Tough all-rounder

CONS
- Most expensive

PROS
- Fastest in straight line

CONS
- Less striking looks

Blue Mantis

Price: £39.99/$TBA

Get it from: www.amazon.co.uk

Although the cheapest of the three vehicles in this roundup, the Blue Mantis buggy arguably delivers the sharpest styling, with heavily angled Batmobile-type lines and a cool paintjob. The large flared rear wing and front bumper add to this, granting the Mantis a streamlined and aggressive stance when driving.

On test it was one of the best-handling vehicles, with a low profile and thick exposed tyres granting it good grip on most surfaces and allowing fast changes of direction at speed. This gave it an agility not matched by its competitors.

However, we had one reservation with the Mantis – the exposed suspension struts and wheels which were liable to get bashed in any collision. While these are easily replaceable, it seemed an avoidable weak point, which is a shame considering the chassis' construction out of shock-resistant high-tech polymer.

Overall, despite our reservations, the Mantis delivers some tidy tech for the price.

Verdict: ★★★☆☆

Wild Horns

Price: £59.99/$TBA

Get it from: www.amazon.co.uk

After seeing this issue's awesome feature on monster trucks come alive, getting hands-on with the Wild Horns – a 1:18-scale RC monster truck – was a real pleasure. Aesthetically it is a cross between a real-world monster truck and a speedboat, with a high-sitting vented chassis positioned over thick, tapered tyres.

In terms of performance, the Wild Horns was a great all-rounder when on test. Its construction quality was excellent, with repeated crashes and flips seemingly having no impact on the unit. Despite its high-sitting chassis, it was also nicely weighted and not as cumbersome in terms of cornering as you might expect – or as slow off the mark.

The real plus-point with the Wild Horns was its ability to perform well across a wide variety of surfaces and conditions, both inside and outside. All of the models' electronic systems are water and dustproof, but this vehicle in particular seems ready to tackle anything that's thrown at it.

Verdict: ★★★★★

Road Rider

Price: £49.99/$TBA

Get it from: www.amazon.co.uk

The third and final remote-control vehicle in this group test is an actual car. The Road Rider is themed as a futuristic American muscle car, with a long and narrow profile, thick rear wheels and chunky streamlined chassis. However despite the obvious styling, aesthetically the Rider was the least impressive vehicle on test, especially considering the flamboyant nature of its competition.

But while it was disappointing visually, the Rider made up for it in speed and acceleration. Of all the vehicles trialled it was the fastest in a straight line and, despite not being as agile as the others, performed well across a selection of environments. This said, its best speeds were clocked on flat, even surfaces.

Sitting between the Mantis and Wild Horns in cost – and arguably performance too – choosing this over the others really comes down to your own aesthetic tastes. With no major downsides to report on though, the Rider has to score highly.

Verdict: ★★★★☆

The Carbon Age

Introducing the multi-award winning Debut Carbon from Pro-Ject Audio Systems. The Debut record player is an icon of the entry-level audiophile market, and this latest incarnation elevates the model to a new level of audio quality.

Debut Carbon

Brand new one-piece 8.6" Carbon Fibre tonearm - New motor isolation set-up - Upgraded 12" platter with higher mass - New mains supply method - Cable junction box - Ortofon 2m Red Pre-Fitted - Available in 7 high-gloss colours

Pro-Ject Audio Systems is distributed in the UK by
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Pro-Ject
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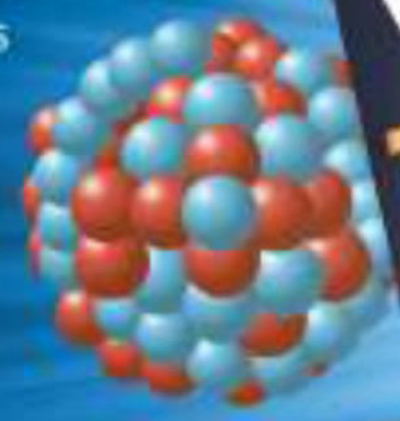

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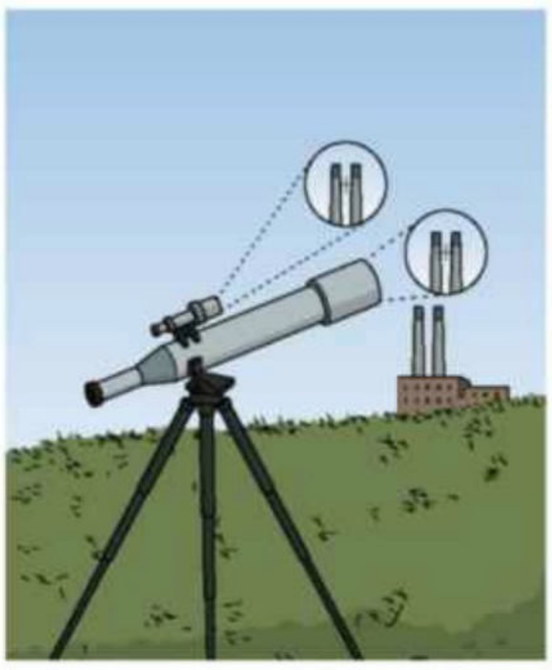
Use a telescope

Want to look at the stars but not sure where to start with your new telescope? Here are some tips for novice astronomers

1 Know your equipment

There's nothing worse than going out at night with your new telescope hoping to see some stars and discovering that you can't see what you're doing. Practise aiming and focusing in daylight. Don't be surprised if you find yourself looking at an upside-down building; space doesn't have an 'up' or 'down' so telescopes don't have a prism to flip the image. Always be careful to avoid looking in the direction of the Sun.



2 Align the finder

Telescopes have a smaller finderscope that has a low-powered wide field of view, allowing you to orientate yourself more easily when studying the vast night sky. Make sure that the finder is aligned with the main scope by first focusing on a static object, like a tree or a chimney; adjust the main scope and the finder until the object is centred in the crosshairs of both before moving on to the next step.

3 Start with the Moon

The Moon is a great place to start for beginners – it is a big target and there's a lot to see. Once you have Earth's natural satellite in your scope, adjust the focus until the blurry image starts to become brighter and smaller. The Moon is very bright, so it can help to leave a white light on nearby to prevent your eyes from adjusting too much to the dark – this keeps your colour vision active, helping you to discern more detail.

4 Invest in a star map

Star maps are based on specific latitudes, so be sure to get hold of one that corresponds to your location. As our planet is constantly on the move, the sky also changes depending on the time of year, so rotate the wheel on the map so that it matches the current date. If you're in the northern hemisphere, use the North Star to orientate yourself; in the southern hemisphere you can use the Southern Cross (Crux).

5 Look harder

Don't be afraid to experiment with the focus to try to get the image a little bit sharper. When you first start out it can be challenging to see details because the atmosphere interferes with the light, making it shimmer and flicker. But don't be disheartened if Mars just looks like a fuzzy orange blob to begin – with practice you can train your eyes, and the more you look, the more details you'll begin to notice.

In summary...

Learning to use your telescope properly takes a bit of practice, but the secret is to take your time, get to know your equipment, start out with easy objects and train your eyes to notice new details. Carrying a sketchbook and recording your observations can help you to focus on picking out extra features and also serves as a great record of your progress.

Learn more

If this has only piqued your appetite for telescope tips, check out our sister title **All About Space**, which has an entire section dedicated to amateur stargazing every issue.

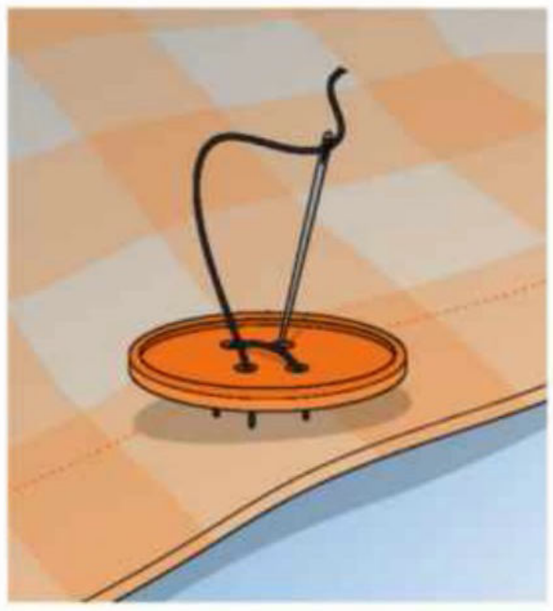
NEXT ISSUE
- Surf like a pro
- Grow your own tomatoes

Sew a button

Don't chuck away that shirt – reattaching a button is a lot easier than you might think...

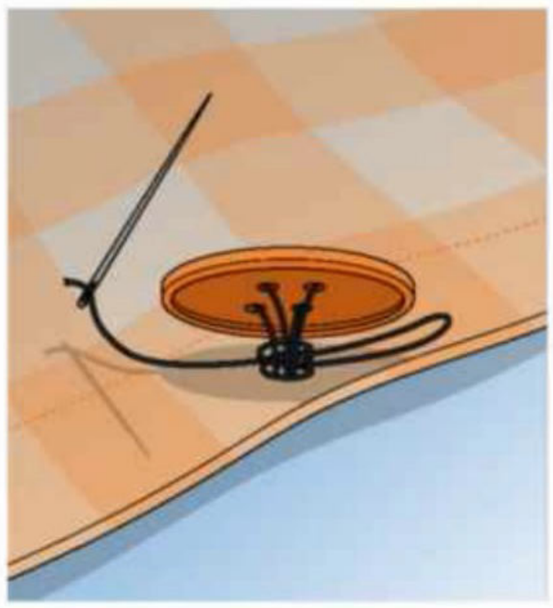
1 Secure the button

To kick off, thread your needle and tie a knot in the end of the cotton, then mark where the button needs to go and push the needle through from the inside of the garment to the outside. Make several alternate stitches through the holes in the button so that they criss-cross over one another. At the end of this process the needle and thread should be on the reverse side of the fabric.



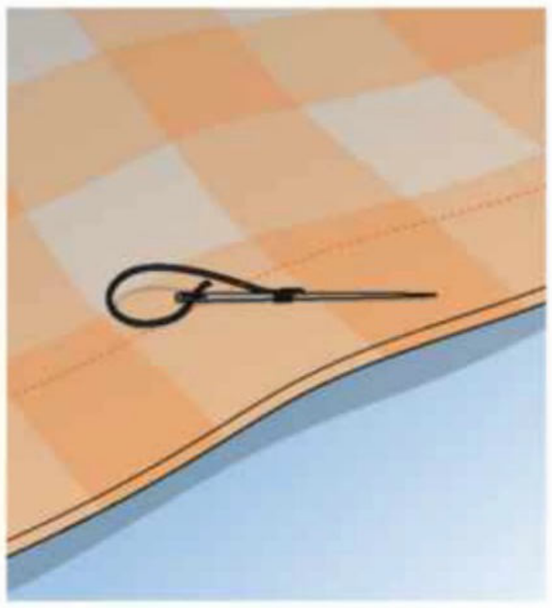
2 Make a shank

Now the button is on, you need to strengthen the stitching underneath and pull it all together to make a tight shank, so that the button will fit neatly through the buttonhole. To do this, poke the needle back through the fabric so it comes out between the material and the button, then wind it round the underside of the button five or six times to create a tight bundle around the various threads.



3 Tidy up

Once the shank is finished, push the needle through to the back of the fabric once again and make three or four small stitches on top of one another which will prevent the thread from coming loose. To finish, loop the needle through these stitches and tie a knot. Cut the thread about five millimetres (0.2 inches) away from the knot and your garment is restored to its former glory.



In summary...

Sewing a button back onto a shirt or a coat is actually a pretty straightforward job. All you need is the button, a length of thread, a needle and a few spare minutes. Buttons sewn on by hand often stay on much longer than those sewn by machine in factories, and the neater and more even your stitches, the stronger they will be.

TEST YOUR KNOWLEDGE

ENJOYED THIS ISSUE? WELL, WHY NOT TEST YOUR WELL-FED MIND WITH THIS QUICK QUIZ BASED ON THIS MONTH'S CONTENT?

1. When is the solar-powered spacecraft Juno (pictured) scheduled to get to Jupiter?
2. What is the semi-precious gemstone amber made of?
3. When was *On The Origin Of Species* first published?
4. What is pumped around an Advanced Bomb Suit to keep the occupant cool?
5. Does colour blindness occur more frequently in men or women?
6. How many stars does the exoplanet Kepler-16b orbit?
7. Which cell of the human immune system produces antibodies?
8. What are stalactites and stalagmites made of?
9. Which bacterium has been found to be responsible for stomach ulcers?
10. What are the largest plankton collectively known as?

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ISSUE 47 ANSWERS

1. Pinakes **2.** Marsh **3.** 1972 **4.** 14% **5.** 1601 **6.** 30cm **7.** National Ignition Facility **8.** -18˚C **9.** 4.54 BYA **10.** 10.4km²

INBOX

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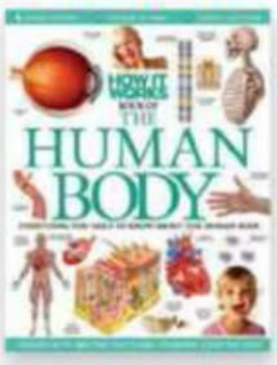

WIN HOW IT WORKS BOOK OF THE HUMAN BODY

The winner of this issue's Letter of the Month will receive a copy of the hugely popular **How It Works Book Of The Human Body**, your indispensable guide to human biology.

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Could black holes be wormholes? Let us know your thoughts...

Letter of the Month

Multidimensional query

Hi HIW,
My friend and I have come up with some theories. Firstly, everything – even ink – has a height, so surely the lowest number of dimensions is three? Because light isn't really matter, or is it? Secondly, could black holes be wormholes? We thought that you couldn't really make an unseen tunnel through space because a black hole is surrounded by space, right? What if it were shaped like an egg-timer? Thirdly, we read that eventually the universe will be flat. I was thinking that if the universe was a ball unravelling as time passed, another universe could be formed inside the centre, and this universe could be the centre of another universe, and so on. Can you help us find out if these theories are correct?
Abraham Keefe

Thank you for your thought-provoking letter, Abraham! These are some really interesting ideas about space-time and the structure of the universe. For such big and complex questions we think it would be good to get a few different opinions on the subject, so if any physics-minded readers would like to write in with their views on these ideas then we will collect together the best ones and publish them in the next issue of the magazine.

Red meat turns brown for the same reason some metals go rusty: oxidation

Why does red meat go brown?

Hello,
While working as a butcher in the past I noticed that if I cut a piece of meat in two and then allowed the two pieces to come into contact with each other a brownish discolouration would appear at the contact points. I am wondering what chemical process is going on?
Brett Williams

Hi Brett, thanks for writing in with your query. When raw beef is first exposed to air it turns bright red because the iron-containing protein myoglobin binds to oxygen, much like haemoglobin in the blood. If the iron in the myoglobin becomes oxidised and changes from its ferrous to its ferric form, the colour of the protein changes from red to brown.

Never-ending argument

Hi,
What is perpetual motion and how does the idea work? My dad and I are having an argument about whether it is possible or not. Can you settle this argument once and for all in the next issue?
Charles Dennis James Wright

It's a fascinating notion, Charles, and we would love to help settle your 'debate' with your dad – stay tuned for the answer in an upcoming issue.

Flash mystery

Dear HIW,
I live in a very rural area and every time I walk outside at night I always look at the stars. One night I was looking up and there was an extremely bright flash from the left side of the star I was looking at. Approximately five minutes later there was another bright flash off the left side of the star again. Do you have any idea what I saw? Is it a gamma-ray burst? Or some sort of nuclear explosion?
John Shampnoi

Our friends over at All About Space magazine say that what you saw is likely to have been an iridium flare from an orbiting satellite. The Iridium communication satellites are in low Earth orbit (LEO) and occasionally

Mephisto is the last surviving A7V tank in the world so be sure to pay it a visit if you're ever in Brisbane

light from the Sun is reflected by their solar panels creating a brief, bright flash visible to us below.

An explosive objection

Hello,
[In issue 45] you stated that energy can never be created nor destroyed. I appreciate this is the first law of thermodynamics, but energy must have been created at some point in time. For matter and antimatter to have been created, there needed to have been energy beforehand. Therefore, there is a massive flaw in this theory. However, there is another theory that may suffice. I ask you to imagine two extra-dimensional waves, waving randomly. At occasional points, they collide. These collisions form universes. Love the mag. Keep on printing.
Jordan Godley

Unfortunately there is currently no definitive answer to this debate, Jordan. The first law of thermodynamics is based on observations of the physical properties of energy and matter in the closed system that is our universe. It is therefore incredibly hard to predict whether the laws would still be applicable before the universe, as we know it, came to be. We would love to hear others' opinions on the topic.

Forgotten tank

Dear Sir/Madam,
Thanks for a wonderful publication, always full of very interesting articles. Issue 33 has an article about the A7V German tanks from World War I, and the last paragraph states that 'no original A7V has survived'. You may be interested to hear that the only remaining original A7V is on display at the Queensland Museum in Brisbane, Australia, where I live.
Ross Brett

Hi Ross, thank you so much for your letter. It's great to know there's still a surviving A7V tank out there!

What's happening on... Twitter?

We love to hear from **How It Works'** dedicated readers and followers, with all of your queries about the magazine and the world of science, plus any topics you would like to see explained. Here we select a few of the tweets that caught our eye over the last month.

Lee @Lee_1609
@HowItWorksmag
Thoroughly enjoyed issue 46, now I've got to persuade my school to subscribe though!

Adam Bennett @Adambennett7
@HowItWorksmag Why does air appear wavy in hot weather?

Lilinha Espindula @LilinhaAngel
@HowItWorksmag How fantastic! I am a biologist and would love to teach science at home to my little boy! The kit looks fun! :)

Maria Pipe @Mariapipe81
@HowItWorksmag
Would be perfect for my daughter and her school work, fantastic company, AWESOME competition, fingers crossed xxx

Emma Gallagher @emstargally
@HowItWorksmag
My three-year-old son at the Science Museum already has a passion for how things work

Chris Bull @sparky61
@HowItWorksmag
This looks great fun :-)

"For matter and antimatter to be created, there needed to have been energy beforehand"

HOW IT WORKS

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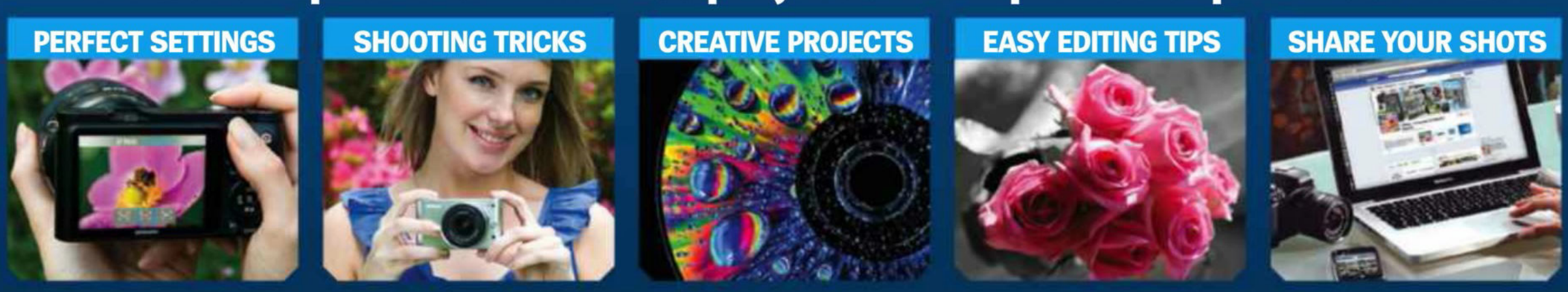

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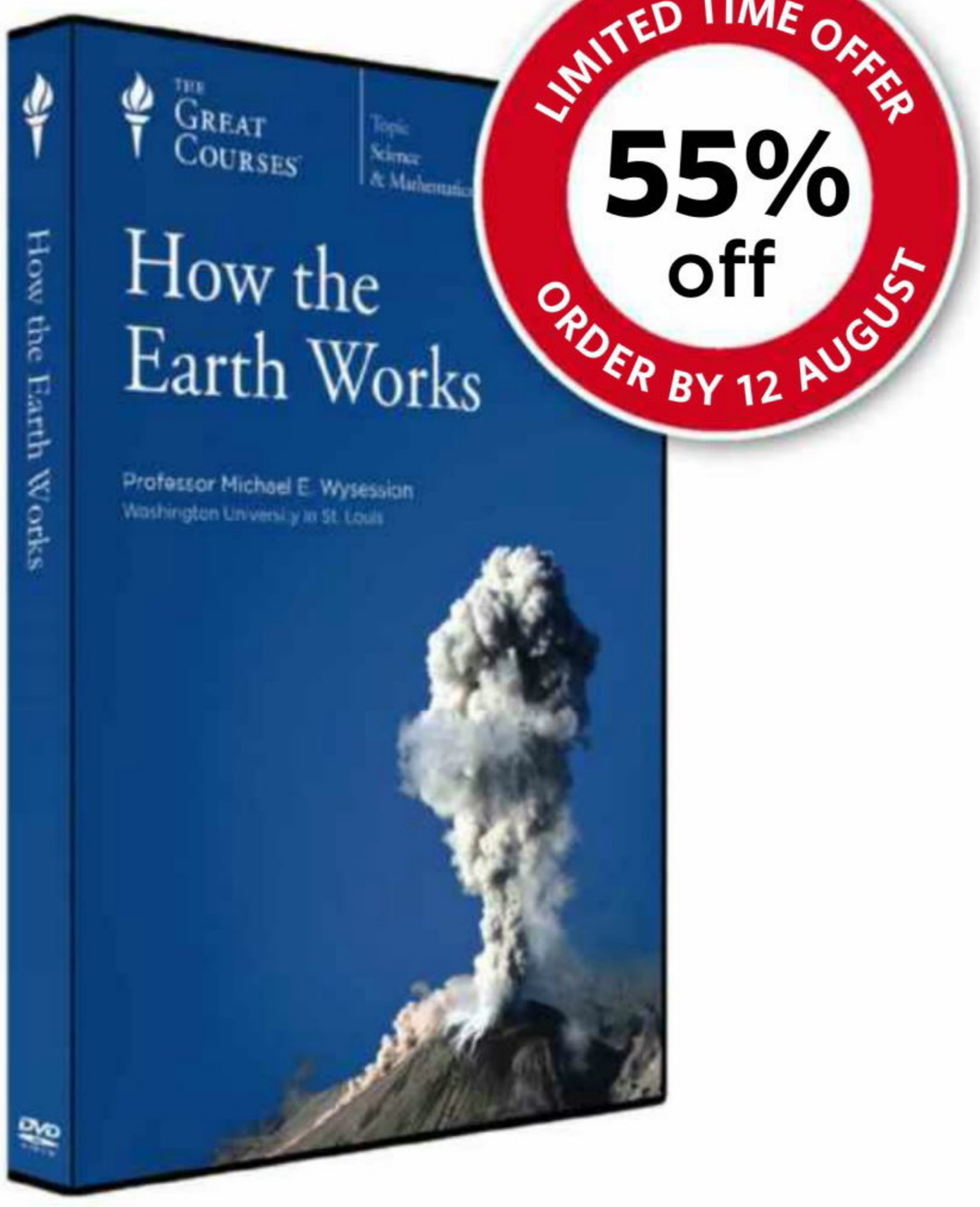

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